CPE Comments and Topics

Oil-from-coal—another agonising reappraisal?

VERY soon the Ministry of Power will have to consider the recommendations made by the Wilson Committee; once again another fuel policy will have to be reconsidered from first principles. The terms of reference of the committee, appointed by Lord Mills in 1959, were to review the work done in recent years on the development of process from coal to produce products of a chemical, gaseous or liquid hydrocarbon type; and to make recommendations as to the direction of future research and development on such processes which appear to hold promise of industrial application. The report of the committee on coal derivatives (H.M.S.O., August 1960) states in the introductory paragraph that the actual use of coal to produce power and coke was outside the committee's terms of reference —the central theme of their work was only concerned with the complete gasification of coal.

The main uses of coal in this country are, firstly, for direct production of heat and power (140 million tons p.a. coal consumption) and, secondly, to produce coke, coal gas and associated by-products (50 million tons p.a. consumption). A third and relatively small use is in the production of chemicals (other than those based on carbonisation by-products), but this accounts for only $1\frac{1}{2}$ tons coal p.a. By increasing the production of chemicals from coal (including synthesis of hydrocarbons) the maximum coal consumption to be expected would only be $2\frac{1}{2}$ million tons. Clearly, therefore, the potentialities of coal as a chemical raw material will not to any appreciable extent solve the long-term worries of the coal industry.

The two methods available for the production of hydrocarbons from coal were fully discussed in the report. The first entails the thermal breakdown of the raw material under pressure in the presence of hydrogen. This process, already developed in 1914 by Bergius, was adapted by I.C.I. from 1935 until the outbreak of the second world war. The second method is a two-stage process. In the first stage coal is completely gasified by reacting it with steam and air to form a mixture of CO and H_2 (known as synthesis gas); in the second stage this synthesis gas is transformed catalytically into various liquid and gaseous hydrocarbons. The latter stage is known as Fischer-Tropsch synthesis and was first discovered in 1925.

The report clearly shows that the first method, hydrogenation, is definitely less economic than Fischer-Tropsch synthesis. As regards the second method, complete gasification was first developed by Lurgi in Germany. The process involves injection of steam and oxygen through a fixed bed of coal which is transformed into a mixture of CO_2, CO, H_2 and a little CH_4. The Gas Council has been investigating this process for town gas production; its cost estimates have been sufficiently low to be economically attractive.

Before 1947 Fischer-Tropsch syntheses centred around conventional fixed-bed reactors whose mechanism is fairly well understood—indeed the German firms Ruhrchemie and Gewerkschaft Rheinpreussen have carried out similar pilot and semi-works scale development on this type of reactor for the last 20 years. From 1947-53 a study was made in this country of the fluidised-bed system, much of the work having been pioneered by I. G. Farbenindustrie and the Carthage Hydrocol Co., U.S.A. Many advantages over fixed-bed reactors were noted, but its serious limitation—that this reaction can only employ hydrogen-rich feed gases to produce a product consisting predominantly of low-boiling liquid hydrocarbons—has prevented it from being adopted.

Developments of the slurry-type synthesis were initiated in 1947 and were originally expected to be the most economical under U.K. conditions. In this reaction, synthesis gas is passed through a suspension of powdered iron catalyst in molten wax, volatile products pass out of the reactor with the effluent gases and by means of a subsequent three-stage fractional condensation a wide boiling range of hydrocarbons is obtained.

The committee's findings, having taken all these points into account, are quite categorical. The cost of making synthesis gas from coal was found to represent the major part of the total oil-making process; this would about equal the value of the products made by the subsequent Fischer-Tropsch synthesis and there would therefore be no margin left to provide for labour, overheads, etc. As a result the committee has recommended that technological work on Fischer-Tropsch synthesis be wound up within the near future. However, the production of town gas by the Lurgi process was shown to be the best available method provided the gas is suitably enriched with petroleum products.

No one can quarrel with the way that this task was undertaken and carried out by the Wilson Committee, nor with the conclusions reached. The main economic causes behind the findings are, of course, that during the past few years world petroleum prices have fallen and U.K. coal prices have risen—a trend that is not expected to level off in the near future. The government and its technical advisers have, for better or worse, placed all their money on petroleum.

Is this not a propitious moment for the government to co-ordinate once and for all its various power programmes whilst distinguishing between short-term and long-term objectives? The lesson we must learn from the Wilson Committee report is that in the long run too many scientific and technical cooks carrying out uncoordinated development work in the same field will, in the end, spoil the broth—and we can ill afford to spoil our broth too often!

New fuel cell

A NOTEWORTHY addition to the considerable range of fuel cells was recently developed at the Shell Research Centre, Thornton. The usefulness of an economic fuel cell is quite obvious—it need hardly be emphasised that between 60 to 85% of fuel energy is lost as waste heat when fuels are burned in turbines or internal combustion engines. By directly converting chemical energy of a fuel to electricity without using an intermediate heat engine, this waste is reduced to between 20 and 30%.

The Thornton fuel cell operates at atmospheric temperature and consists of thin porous electrodes separated by an electrolyte. Either acid or alkaline electrolytes can be used, but in general an acid cell has a major advantage because it is free from troubles due to carbon dioxide present in the atmosphere and in fuel combustion gases, which destroys the activity of alkaline electrolytes. The fuel, which is generally hydrogen, but will eventually be a hydrocarbon, is fed to one electrode and oxygen or air to the other. When run on hydrogen and oxygen at a pressure of 3 p.s.i., current densities of 70 amp./sq.ft. can be readily obtained with both types of electrolyte at room temperature. If air is substituted for oxygen there is little loss in performance and as the cell warms up to 60°C. the output is doubled. (An electric battery of comparable capacity would be eight times as heavy and occupy five times the volume of the Thornton cell.) Multiple fuel cells with up to six cells/in. have already been constructed and it is now believed that units having a power-to-weight ratio of 50 W./lb. are realisable.

Uses for lignite

LIGNITE—an intermediate product in the formation of soft coal—was shown to have interesting possibilities as a raw material for rubber plasticisers and anti-oxidants. This was recently reported by R. A. Clark of the Battelle Memorial Institute at a meeting of the American Chemical Society's division of rubber chemistry. The most promising derivatives of lignite fall into two classes. The first, HBMS, is extracted from lignite by methanol and compares favourably with standard anti-oxidants. The second, HBHS, is extracted with hexane and is effective both as an anti-oxidant and a plasticiser. The hexane and methanol extracts can be blended to give an optimum balance of ageing properties in rubbers. The methanol extracts were found comparable to two commercial anti-oxidants with respect to their effects on tensile strength and elongation of rubber. After four days' ageing, 5 and 10 parts of methanol fractions per hundred parts natural rubber were found to have similar properties to 2 parts per hundred parts of PBNA (phenyl-beta-naphthylamine) and DBPC (di-tert-butyl-paracresol). Blends of hexane extract showed great promise as plasticisers. Hexane soluble fractions—both high and medium boiling range—were fully compatible at levels of 10, 20 and 30 p.h.r. and found to be easily incorporated into SBR-1500 (butadiene-styrene rubber).

According to Dr. Clark these experimental results indicate that the general performance of these chemicals exceeded that obtained for the hydrocarbon softener control, with HBMS slightly more efficient and HBHS slightly less efficient in plasticising action than the control. While the composition and properties of these products were carefully controlled in production, it is possible to adjust operation conditions to tailor-made fractions with various physical properties. All the studies made with lignite tar fractions indicated that these materials have a high degree of compatibility with rubber and, even using up to 30 p.h.r. of the hexane soluble fractions in SBR, neoprene and nitrile rubber, no signs of sweating-out were found.

To convince rubber manufacturers of the suitability of these new derivatives, more extensive tests will have to be carried out. The major attraction is definitely their low cost—standard anti-oxidants are sometimes the most expensive ingredients in a rubber formulation. It is often suspected that cheap rubber compounds contain no anti-oxidants at all and if there were a useful low-cost range of anti-oxidants on the market one could hope for an improvement in general quality.

'Inconel' v. stainless steel

MATERIALS used for construction of steam generation systems for pressurised water nuclear power plant must pass very stringent requirements. These materials are exposed on one side to primary reactor water which is the heat-exchange medium flowing past the radioactive fuel elements, and on the other side to secondary boiling water. On the primary side, corrosion products can be transported to the fuel elements, activated and transported back. It is imperative, therefore, that there is no more than a minimum of loose corrosion products, that the induced radioactivity of these products is low and also that the two waters are not mixed. These requirements call for excellent fabrication characteristics and good corrosion behaviour. In addition the materials must have suitable physical and mechanical properties and be reasonable in cost.

Austenitic stainless steels have been used extensively in this application, but, unfortunately, are susceptible to stress cracking under some conditions which conceivably might be encountered in heat-exchanger systems. For instance, chlorides which are likely to be present in secondary boiler water might accumulate in crevices and be subjected to wet vapour phases plus oxygen to promote stress-corrosion cracking.

Inconel, however, resists stress-corrosion cracking in chloride and alkaline conditions. In the February issue of *Corrosion* (1960, **16** (2), 79) the behaviour of this material for service steam generation systems was discussed. A normal mill production heat of *Inconel* was selected for the tests and, in addition, a heat of unusually high carbon content and a heat of unusually low chromium content were included. These materials were subjected to numerous heat treatments to ensure that they could not be damaged in this fashion. As a reference material, type 347 stainless steel was

included. Tests were conducted in simulated primary and secondary reactor waters. It was found that *Inconel* forms a tightly adherent varnish film in the waters studied, which contributes a relatively small amount of corrosion product to a high-velocity stream of primary water, similar in fact to the austenitic stainless steels. Moreover, the *Inconel* alloy did not suffer inter-granular attack or stress-corrosion cracking in reactor waters.

Reorganisation at the N.C.L.

SEVERAL important organisational changes have taken place in the National Chemical Laboratory during the past year. The annual report for the year 1959 states that during that year the Microbiology Group was disbanded, the National Collection of Industrial Bacteria was transferred to the Torry Research Station and the Chemical Engineering Section was transferred to Warren Spring Laboratory. Undoubtedly these changes have been motivated by a desire to streamline much of the research carried out by the Department of Scientific and Industrial Research. It is inevitable that many government research stations pursue research along parallel lines; the cause for this is that so many establishments had a different historical background before they were grouped under the umbrella of the D.S.I.R.

To argue that research carried out by two or more laboratories along similar lines is in every case wasteful, is as fallacious as it is to argue that it is in every case beneficial. Each case must be judged on its own merits by a central co-ordinating body. The N.C.L. now feels that both microbiological and chemical engineering research should be pursued at other establishments and that work on high polymers should be confined to research on polymer membranes, the synthesis of special-purpose resins and the investigation of materials of high-temperature stability.

The N.C.L. now has only six organisational groups, which are:
1. Extraction of Metals Group (previously Radio-chemical Group).
2. Inorganic Group.
3. Chemical Thermodynamics Group.
4. Corrosion Group.
5. New Materials Group.
6. Radioisotope Applications Group (at Harwell).

The chairman of the laboratory, Prof. C. E. H. Bawn, has mentioned in his report that, in order to ensure the continuance of adequate liaison between the N.C.L., executive government departments interested in the work, the U.K.A.E.A. and the nationalised industries, arrangements have been made for the director to call periodic meetings of representatives of these bodies. In this way it will be possible to give them an account of the progress of the work and also to exchange opinions and seek their views on the work which they consider is needed in the future. This is certainly a most important step towards co-ordination at all levels; it cannot fail but reflect the wind of change which is now blowing so efficiently through the corridors of D.S.I.R.

Canadian approach to nuclear energy

CANADA seems to be showing excellent form in the international nuclear 'steeplechase'. Nowadays when every country, whether it can afford to or not, is constructing reactors for research, power and (not least) military purposes, Canada is candidly proclaiming that a single type of reactor system can completely satisfy her conditions. This was recently stated by Mr. J. L. Gray, president of Atomic Energy of Canada Ltd., in an address to the 33rd Inter-American Symposium on the Peaceful Application of Atomic Energy. Canada is the world's second largest *per capita* consumer of electric energy, and she has extensive hydro-electric and fossil fuel sources, many of which are still untapped. Unfortunately, many of these sources are too far away from load centres to make their use economic. Hence the development of nuclear energy in these regions should greatly help in satisfying to some extent the continuing rise in demand for electricity. The largest demand for additional power in the near future will come from an area that already depends on imported coal for its lowest cost thermal power, that is the southern system of the Hydro-Electric Power Commission of Ontario.

Canadian reactors are all based on the heavy water, natural uranium system. The reasons behind this choice are quite sensible, because of Canada's large indigenous uranium resources but lack of facilities for either enriching natural uranium or reprocessing the spent fuel. By using heavy water, which is the best moderator from a nuclear point of view, natural uranium can be used rather than enriched uranium; this should result in lower-cost power with no fuel reprocessing problems. A first step along the road to developing Canadian power reactors is the construction of the prototype station NPD near Chalk River which will generate 20 MW. electricity. This is expected to be in operation by next year and will provide valuable information on the economics of the fuel cycle. The second project is a full-scale station generating 200 MW. from a reactor known as CANDU similar in many respects to NPD. Construction of this has already started at Douglas Point and the station should be in operation by 1964.

It is expected that by aiming at a good neutron economy, a burn-up of 10,000 MW. days/tonne can be achieved from *Zircalloy*-clad natural uranium oxide fuel, without reprocessing (compared with 3,000 to 4,500 MW. days/tonne in other natural uranium reactors). However, this basic reactor design is only expected to be competitive in sizes above 200 MW. In the medium-size range (which many Canadian utilities will need) a heavy water-moderated reactor with an organic coolant shows greater potential promise.

In future issues we shall describe the heat-exchange system of the CANDU reactor, an installation of great originality. Confidence in its success has already been shown by the Indian Department of Atomic Energy, which co-operated with the Canadians in the construction of the Canada-India research reactor recently completed.

Pressure vessels

DESIGN and construction of pressure vessels in this country is carried out by a relatively small number of firms. In view of this fact, relevant know-how for pressure vessel design is extremely valuable and hard to obtain. Design codes usually lay down minimum general requirements, so that a designer can please himself which code he selects from the following:

B.S. 1500
A.O.T.C. rules (Associated Officers Technical Committee)
A.S.M.E. unfired pressure vessel code
B.S. 1113 (Various design codes for boiler plant)

In addition there are the private specifications of large companies, as for instance British Petroleum, Shell and I.C.I. These companies usually quote their own codes when issuing an enquiry. It must be noted that the British codes only cover low-alloy and carbon steels but not stainless steels; for stainless-steel pressure vessels each manufacturer has his own (personal) specifications.

This state of affairs at first sight seems slightly anarchic; yet it has worked quite satisfactorily so far. The law requires every pressure vessel to be insured and therefore insurance companies usually have access to the vessel during or after fabrication for testing purposes—the tests they carry out are, again, selected by the companies. In his article on design of pressure vessels in this issue, Mr. Haftke has pointed out that, as far as nuclear reactor vessels are concerned, a balanced and empirical approach has everywhere yielded good results, and this despite the many novel factors that have had to be taken into account, such as extra thickness of the vessels, extra weight, new applications of welding techniques and irradiation on welds. The general importance of pressure vessel design in chemical engineering need hardly be stressed. It can only be hoped that in future more will be published by designers and that a uniform code will soon be drawn up which is acceptable and adhered to by all fabricators in this field.

Methods for strengthening glass

THE possibility of replacing metals by glass as structural materials may be the result of a new technique developed at the D. I. Mendeleev Institute of Chemical Technology, Moscow, and described in recent *Proceedings of the Academy of Sciences of the U.S.S.R., Chemical Technology Section*, volume 129. Using a new technique of combined chemical and thermal treatment, the bending strength of glass so treated became greater than that of widely used steels. The experiments were carried out with industrial sheet glass, which was first softened by heating in a furnace at 200°C. and then quickly immersed in a heated organosilicon liquid bath. Hardening was achieved by constantly decreasing the temperature of the organosilicon liquid. The glass specimens were subsequently removed from the bath and dried at 200°C.; higher temperatures were found to bring about a considerable relaxation of the residual stresses in glass.

This process was found to increase the bending strength of 3-mm.-thick glass by as much as 11 times, to 55 kg./sq.in., while with thicker glasses the bending strength was increased by an even higher ratio. This marked increase in strength was due to the simultaneous hardening of residual stresses, and the formation (at the moment of quenching), of a silicon-oxygen polymer which heals the micro-cracks in the glass surface. It is interesting to note that the internal residual stresses produced in this way are only slightly greater than those produced during normal hardening of glass in air. It is therefore evident that the success obtained depends on the nature of the polymeric film formed, which acts as a protection.

Make mine music

THE age of miracles is not past. This was brought home to us recently when we read a news item reported in a responsible daily paper, whose New Delhi correspondent had reported that India may soon broadcast music to growing crops. Experiments had apparently revealed that a rice paddy field, which was ' excited ' by music, produced from 22 to 58% more rice; the technique involved broadcasting soft music to standing crops from strategically located loud-speakers. ' The Indian government is checking the effectiveness of this technique ', said the Minister of Agriculture, ' and if results are successful it might consider large-scale use of music to increase food output '.

No doubt a hypothesis will soon be propounded that, in the same way as photosynthesis is responsible for conversion of sunlight to energy, ' auro-synthesis ' converts sound waves into plant food. A little daring perhaps, but in this day and age we must be bold in our speculations. Let us then try to apply auro-synthesis to chemical reactions. Would it not be valid to assume that under certain conditions complicated chemical reactions might be initiated, or possibly catalysed, by the judicious application of music. Must we not therefore have to reckon with ' auro-catalysts ' in future ?

Our imagination has no bounds and we can visualise the day when the London Philharmonic Orchestra are hired by leading chemical manufacturers to carry out complicated chemical reactions. Naturally the type of music played would influence (a) the yield and (b) the rate of reaction. Perhaps the ' Symphonie Fantastique ' should be played when synthesising some of the newly developed complex proteins; the ' Pastoral Symphony' would be suitable for the production of fertilisers and herbicides. In this way most composers will be suited to a particular reaction—for an exothermic reaction the music would have to be cool and soothing, whilst for an endothermic reaction it would have to be loud and passionate. However, we must counsel caution when applying atonal music; the reaction rate might be so violent as to cause fission. Suggestions for further musical catalysts are always welcome.

Design and Construction of Pressure Vessels

By J. J. Haftke,* B.Sc.(Eng.), A.M.I.Mech.E.

The problems confronting both designers and fabricators of special-purpose pressure vessels are complex. Most design codes in practice only lay down minimum general requirements and designers must judge every case on its particular requirements. It is needless to stress the dangers of under-design, but it cannot be overemphasised that too conservative a design is both incompetitive and ·wasteful. In this article the author discusses the broad principles involved in the design and construction of pressure vessels and illustrates this by describing some particular problems associated with the fabrication of one of the nuclear reactors at present under construction at Hinkley Point.

Fig. I. Manufacture of shell rings of the Hinkley Point steam-raising units at Babcock & Wilcox Ltd. Dalmuir works.

SINCE it would be quite impossible to cover even briefly this subject in a short article, an attempt is made to deal with the general problems of pressure vessel design for the nuclear power field, leaving out the rudimentary principles of detailed pressure vessel design in general, which are adequately covered by readily available literature. The problems of construction and inspection of pressure vessels will be dealt with on a similar basis, but, in addition, attention will be focused on such aspects of these problems as are of particular interest to the design engineer.

It can be stated broadly that plant design must satisfy four basic requirements of overriding importance:

(1) Functional suitability.
(2) Safety.
(3) Economy.
(4) Speed of construction.

Functional suitability and safety

The primary aim of any design must be its suitability for the particular functions which the equipment is required to perform. The consequence of this requirement, which may not always be obvious, is that it is essential for the design engineer to assure himself that he is aware of all the conditions to which the equipment will be subjected, including not only the normal mode of operation, but also covering the transient and emergency conditions for which the plant is to be designed as well as the relevant aspects of shop manufacture, transportation, erection and testing.

It can be seen that safety forms an aspect of the functional suitability requirement, since no plant can be suitable functionally unless it is safe.

To ensure the safety of the plant, the design engineer must calculate the stresses and deformations in his equipment under all relevant conditions. This means in turn that the behaviour of the equipment must be predictable under all such conditions and that it must be capable of being subjected to theoretical or experimental stress analysis. Bearing in mind the limitations of current knowledge of strength of materials as well as the limitations of both analytical and experimental techniques, this consideration can often lead to the rejection of a seemingly attractive design feature, because of inability to predict reliably the behaviour of such a component under various conditions to which it may be subjected.

The stress analysis aspect is covered in some very broad and basic principles in the various design codes used in the pressure vessel field such as B.S. 1500, the A.S.M.E. code for unfired pressure vessels, the rules of the Lloyd's Register of Shipping and rules of the Associated Engineering Insurers Committee, together with individual specifications often issued by the customer and their inspecting authorities for a particular job.

However, these various codes of practice lay down the minimum general requirements of safety and in some cases the designer will have to take a more detailed view depending on the particular duty of the equipment involved. The formulae and maximum permissible stress levels covered by these codes deal only with the principal, overall stresses present
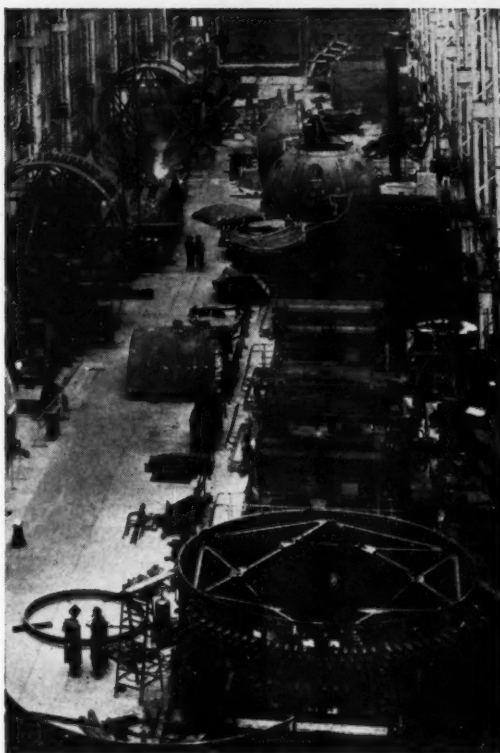
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Fig. 2. Sectional elevation through the reactor vessel at Hinkley Point station.

of failure of the vessel in that particular zone, and must specifically design against each relevant mode of failure.

Thus, for instance, the relevant modes of failure which might be considered for a reactor pressure vessel operating at a moderately high temperature and pressure, and allowing for periodic shut-down cooling and depressurisation would be:

(a) Fatigue.
(b) Excessive deformation due to elastic strain, yield or creep.
(c) Corrosion.
(d) Brittle fracture.
(e) Creep rupture.

(a) Fatigue

An example of a feature of a pressure vessel which must be specifically designed against this mode of failure is the continuous skirt support of the spherical reactor vessel shown in Figs. 2 and 3, which extends into the inside of the vessel forming a means of direct transmission of the weight of the reactor core to the reactor vessel foundations. In the region of this junction between the reactor vessel, the internal skirt and the external skirt a fairly complex stress system exists, consisting of stresses due to the dead weight of the reactor vessels and its internals, due to temperature gradients around this junction, and due to the pressure inflation of the reactor sphere.

It will be readily appreciated that, once the plant is built, the level of the stresses due to dead weight will remain substantially unaltered throughout the lifetime of the reactor. The stresses due to the other two causes, however, will alternate over a range each time the vessel is depressurised and allowed to cool to ambient conditions. In an assessment of the safety of this component against a fatigue failure, it is the stress range which is of primary importance rather than the absolute stress level.

(b) Excessive deformation

There are many components in some of the nuclear pressure vessels for which close alignment relative to other parts is essential for the successful functioning of the plant. One can refer to the charge and control rod nozzles and stand pipes located in, and above, the upper cap of the reactor vessel (Fig. 2). It is clearly necessary to make sure that the accumulative effects of elastic deformation under pressure, any localised yielding which might take place and of long-term creep over the lifetime of the reactor, combined with the

in a pressure vessel, and give practically no guidance to the designer with regard to localised stresses which in any but the simplest and most orthodox configuration will in fact govern the detailed design of the various components of a pressure vessel.

In so far as these localised stresses are concerned, and these are usually associated with local irregularities of shape of a pressure vessel or with local variations in service conditions, such as wall temperature variations, etc., the designer must resort for his information to various technical papers, textbooks and experimental stress analysis and last, but not least, to the experience available within his own organisation.

One of the major problems facing a design engineer is that of having to decide on the acceptability of a certain stress level which he anticipates will be present in the vessel in some localised area. It is unfortunately quite impossible to give any general rules for acceptance limits on localised stresses. The design engineer must carefully consider each case on its own merits, having due regard to the extent of the highly stressed zone, the
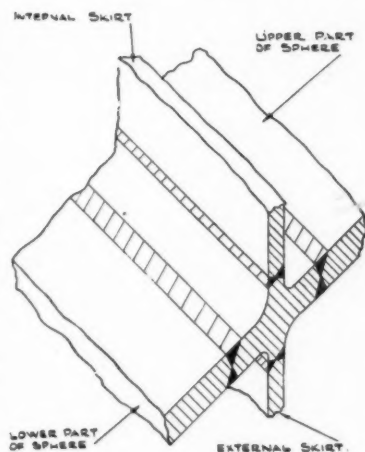

Fig. 3. Detail of cruciform ring at junction of reactor vessel and supporting skirts.

type of stress present, i.e. whether membrane or bending or both, steady or cyclic, whether the stress is of a sustained value, or of the type which would be reduced by some highly localised yielding and, furthermore, must postulate all the possible modes

inevitable manufacturing tolerances, are fully allowed for in the design of the plant, so that they will not prejudice the proper functioning of the control rods and of the charge/discharge equipment.

(c) Corrosion

In present and currently envisaged designs of nuclear pressure vessels, failure, by the impairing of strength of the vessel through corrosion, is not a problem. The effects of corrosion are of significance, nevertheless, because of the possibility of the corrosion products contaminating the primary circuit of the plant. Thus the normal practice used for pressure vessels in many fields, of simply allowing an adequate corrosion allowance in the installed thickness of the vessel, may not represent the correct solution to the problem in the case of components of the primary circuit of a nuclear reactor. This solution must lie, therefore, in the employment of materials of construction (or of suitable internal facings or linings) which are not susceptible to excessive corrosion under the operating conditions.

(d) Brittle fracture

Brittle fracture may affect the selection of the materials of construction, particularly in the case of the reactor pressure vessel, and some adjacent parts of the primary circuit which might be subjected to irradiation during the lifetime of the plant, since it is known that irradiated steel may fail in a brittle manner under conditions less severe than would be required for such a failure in the case of the same steel in an un-irradiated condition.

Whilst the present-day knowledge of the causes and mechanisms of brittle fracture leaves much to be desired, and whilst no experience is yet available of the long-term effects of irradiation in this respect, the designer must safeguard against brittle fracture on the basis of such information as is available.

The materials of construction and the manufacturing methods and welding conditions and techniques must be so chosen as to eliminate the possibility of brittle fracture during construction. This requirement can be satisfied without difficulty by an experienced and competent manufacturer without resort to any techniques or materials of construction which have not been used extensively in the past for pressure vessels outside the nuclear field. Similarly, safeguarding against brittle fracture during the operating lifetime of the plant presents no difficulty for

components which are not subjected to neutron irradiation.

The choice of materials of construction for components subject to neutron irradiation must be so made, in conjunction with the operating conditions of the plant, as to safeguard against the possibility of brittle fracture of these components during operation on the basis of currently available information, and a conservative assessment of this information is clearly fully justified. The final safeguard in this respect is provided by the periodic, destructive examination of samples of the materials of construction subjected to irradiation analogous to that received by the pressure vessels, such tests being carried out throughout the operating lifetime of the plant.

(e) Creep rupture

It is unlikely that creep rupture data will be used as a criterion of design for components of the primary circuit of nuclear plant in the immediate future. For any particular combination of material of construction, operating temperature, stress level and operating lifetime, the creep deformation criterion is likely to govern at levels much below those where creep rupture would become a problem. Thus the main application for creep rupture data is in enabling the selection of materials of construction with good creep rupture ductility.

Accuracy limitations

The design engineer must be clearly aware of the accuracy limitations involved in his calculations and experiments by virtue of the simplifying assumptions that he will have to make, and due to the actual techniques that he will have to employ in his analysis. He must also be aware of the presence of various localised stresses which must exist in any commercially manufactured pressure vessel, due to inaccuracies in shape, local stress raisers associated with small surface imperfections, thickness variations, possible minor weld defects, etc.

It is important from the safety point of view that the design is capable of being manufactured by proved and reliable techniques, and of being inspected by equally sound and reliable methods. It would be easy to place too much faith in non-destructive inspection techniques as themselves a guarantee of the soundness of the pressure vessel, since some faults could escape undetected even by modern methods of non-destructive inspection. The real safeguard, there-

fore, cannot lie in the employment of such inspection methods alone, but in their combination with the employment of such welding techniques as have been proved by experience, and by destructive testing, not to be prone to the production of the type of significant defect that might escape non-destructive examination.

In general, when a choice has to be made between an elegant design from a theoretical viewpoint, and a somewhat less elegant one, but which is easier to manufacture, the second alternative is likely in the end, to produce a sounder and, therefore, a safer pressure vessel as well as a more economic one.

Fig. 4. Manufacture of the main ducting cascade corners at Renfrew.

The same type of practical consideration applies to the selection of materials of construction. It would clearly be a mistake to base the design of, say, a large reactor vessel for which many hundreds of tons of plate material are required, on the use of a steel which, whilst having some very attractive mechanical properties, is particularly prone to, say, local mech-

anical or chemical inconsistencies in the structure of the material, or which is very sensitive to small variations in welding or heat-treatment techniques or with which there is no full-scale fabrication experience.

In principle, the engineer should base his designs on materials of construction and fabrication techniques which are proved and familiar within his own manufacturing organisation. The development of new materials and fabrication techniques should anticipate rather than follow the requirements of the design engineer and it is his duty to give guidance to the people concerned with such development as to what his needs will be in the future.

Economy

This article is concerned with the design of commercial pressure vessels and it would be impossible to over-emphasise the importance of the aspect of economy. It would be quite futile for a pressure vessel engineer to produce the most clever and safe designs if these were never to see the light of day because they could not be made at competitive prices. This situation can easily arise in an organisation where a water-tight division exists between the design engineer and the estimating and costing departments.

It · is essential that the design engineer be aware of the cost of his plant.

The only ways in which a designer can decide whether a particular solution is economic is either by comparing the costs with those relevant to similar successful designs manufactured in the past, or by producing several design alternatives, having these estimated, and comparing the costs. It is important to appreciate here that a cost optimisation limited to a particular pressure vessel, which is but one of the many components of a nuclear power station, can be grossly misleading. For instance, an alteration in the principle dimensions of a particular pressure vessel might lead to a significant reduction in the cost of the vessel itself, but might conceivably result in a far greater increase in costs of other plant components such as foundations, shielding, interconnecting ducting or piping, etc.

To be able to produce a design of a pressure vessel which is competitive as well as safe, the design engineer must be reasonably well informed of the capabilities and limitations of the various plants producing components of his design, of the limitations imposed by transport, and by handling
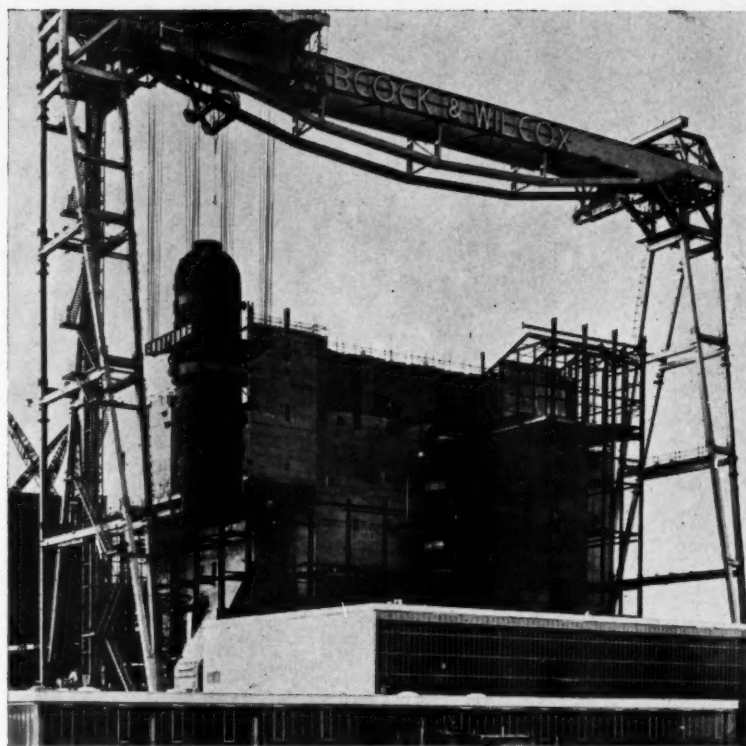

Fig. 5. Lifting of one of the Hinkley Point steam-raising units into position.

facilities and manufacturing facilities at site.

Broadly speaking, the design of various components of a pressure system should be such as to lead to a uniform strength throughout the system, giving similar safety margins and predicted life for all components. It is appreciated that this ideal state of affairs cannot be attained in practice, but at the same time, if a particular feature of a pressure vessel is so conservatively designed as to be out of step with other components regarding the safety margins and predicted life, this is indicative, not of a safety-conscious outlook, but of an uncompetitive design, since the safety of the plant as a whole is in no way improved.

Speed of construction

Commercial plant such as nuclear power stations and the pressure vessels which form some of the major component parts have to be manufactured and put into service within a definite period from the placing of the order for the equipment. The often-heard view that speedy methods are usually cheap as well is a gross over-simplification of the problem. The programme times for the currently constructed nuclear power stations are,

generally speaking, very short. The reason for this is easily understood when one considers the vast capital expenditure involved in these stations and hence the need to put these plants into operation as quickly as possible so as to obtain some return on the invested capital with the minimum delay. Nevertheless, the tightness of the construction programme does lead in many cases to the adoption of rather costly methods of manufacture, particularly where construction at site is concerned.

It is therefore important that the design engineer should be aware of the material delivery times, construction times, shipping times, etc., when deciding upon a particular design of a pressure vessel. Furthermore, he must be able to see a particular pressure vessel as an integrated component of the complete station. It might, for instance, be necessary to acquire a new and special piece of plant for, say, handling at site or for site welding, of a particular pressure vessel. If this is properly appreciated by the design engineer, he will bear it in mind when designing other pressure vessels for the same station, so that they also, if at all possible, can be dealt with by the same plant, and that

the capabilities of this special plant are exploited to their full commercial advantage.

It is hoped that the various aspects of pressure vessel design mentioned briefly above, serve to illustrate the point that the pressure vessel designer must work in intimate collaboration with other departments of his organisation, and that the calculations of the stresses present in his designs should be but a part of his activity.

We now turn to the specific problems associated with pressure vessels which distinguish these from pressure vessels for other types of industrial plant.

Nuclear plant applications

The design and construction of pressure vessels for nuclear power plant applications frequently calls, particularly where the reactor vessels are concerned, for a high accuracy of location and alignment of various attachments, which is not commonly encountered in other fields of pressure vessel utilisation. This requirement clearly influences the particular design solutions and manufacturing techniques, both in the works and at site, but, generally speaking, does not involve the use of manufacturing techniques which are not used in other fields. A good design would provide for the possibility of re-adjustment of location and alignment during the various stages of manufacture to counteract such effects as distortion due to welding, stress relief, etc. It is most important to bear in mind here, that for pressure vessels of the size and weight involved in, say, the C.E.G.B. stage one stations, it is far more prudent to rely for dimensional accuracy on features enabling adjustment to be made towards the completion of manufacture, rather than to hope for the achievement of initial accuracy more appropriate to heavy machinery which is entirely works manufactured and does not involve welding or stress relieving of the almost finished equipment. Whilst the attainment of such initial accuracy may be possible, it is likely to be extremely costly.

Size and pressure

The combination of size of vessel and internal pressure as encountered in some nuclear power plant pressure vessels is not commonly met in other fields.

The effect of this large pressure-diameter product is reflected in the thickness of the pressure vessel and in its weight. Vessels of comparable thicknesses have certainly been manufactured in the past in quite large numbers for other industrial uses, but they have not generally been of a comparable size, enabling fabrication work to be virtually completed at works. Thus, although no new welding techniques are required, for economic reasons it is usually advantageous to employ proportionally heavier handling plant at site, automatic welding equipment at site wherever possible, ' portable ' radiographic equipment for use at site, which would not be used either for smaller vessels manufactured entirely in a supplier's works, or for large, site-fabricated vessels of a smaller thickness.

Radiation effects

The effects of nuclear radiation on the behaviour of constructional materials are a problem unique to some of the pressure vessels for nuclear application. It is clear that this aspect may affect the selection of pressure vessel materials within the range of various commercially proved steels.

To summarise, it can be seen that, apart from the irradiation effects on the properties of materials, no basic new problems are involved in the design and manufacture of pressure vessels for nuclear plant applications, from the point of view of an organisation experienced in the pressure vessel field for other applications. Nevertheless, it must also be appreciated that, by virtue of the size of the plant involved and of the usually extremely short period available for its construction, certain new applications for already known techniques have been developed, although these are governed by considerations which should be classified under the heading of ' productivity ' rather than ' feasibility.'

In addition to the above, it should be stated that, for a variety of reasons, the inspection and quality control standards at present in force for nuclear power plant pressure vessels are in some aspects in excess of those currently demanded for the most stringent classifications of pressure vessels for other industrial uses, mainly from the point of view of numbers of tests involved. These special standards are laid down frequently by the inspecting authorities appointed for a particular plant, or are stipulated in the customer's job specification.

It is worth noting here that, whilst a conservative approach is only reasonable in cases of real doubt, it is unjustified in cases where satisfactory and relevant long-term experience already exists. In this connection it seems appropriate to consider the present approach to non-destructive testing of pressure vessel materials and welded joints.

Normal construction steels and normal Class 1 welded joints are known to contain certain local irregularities in their structure. This has been known for a very long time and the design criteria, the manufacturing methods and inspection techniques, which have been evolved over the years, take full account of this fact.

The clean, trouble-free record of operation of Class 1 vessels in use in conventional plant is a conclusive demonstration of the adequacy of the design criteria and of the inspection criteria employed.

Insistence of higher standards of material inspection or on more conservative design standards, unless coupled with a reduction of design factors of safety, could only be substantiated from a safety point of view if it could be shown either that there has been, in the past, a statistical incidence of failures of Class 1 pressure vessels which could not be accepted in the nuclear plant field, or that nuclear pressure vessels operate under conditions more likely to produce a particular type of failure than any vessels of existing conventional plant.

This is most definitely not the case, since it is in fact the remarkably good record of conventional Class 1 pressure vessels which, together with other factors, has made it possible to proceed with the large-scale industrial nuclear power plant programme in which this country is at present engaged.

A detailed investigation of the various possible modes of failure of a pressure vessel shows that many non-nuclear pressure vessels operate under much more severe conditions with respect to all such possible modes of failure.

The fairly general, broad principles referred to in the preceding part of this article can perhaps be given some additional substance by reference to particular, typical problems associated with the design, manufacture, erection and inspection of the large reactor pressure vessels at present under construction by the author's company at Hinkley Point, as part of their share of the joint construction of the 500-MW nuclear power station for the Central Electricity Generating Board by the English Electric-Babcock & Wilcox-Taylor Woodrow group.

Reactor pressure vessel

The reactor pressure vessel is of spherical shape 67 ft. internal diam. 3 in. thick. It is supported on a cylindrical skirt approximately 30 ft. diam. which extends into the inside of the reactor sphere to form the support of the reactor core.

In the lower part of the reactor sphere are located six main gas inlet nozzles, 6 ft. 6 in. i.d., whilst the corresponding six main gas outlet nozzles of the same dimensions are located just below the perforated top cap of the vessel in which the charge/discharge and control rod nozzles are contained (Fig. 2).

The particular type of continuous skirt support, both for the external support of the reactor vessel and for the internal support of the reactor core and diagrid, have been chosen in preference to a number of discreet supports utilised in some other current designs for a number of reasons, the
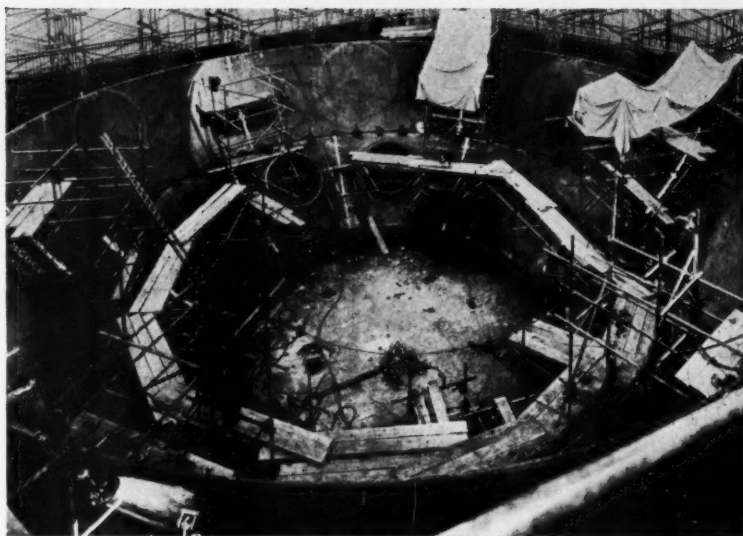

Fig. 7. Assembly of the courses of the Hinkley Point No. 2 reactor vessels in a site prefabrication shop.

Fig. 6. Trial assembly of one of the reactor vessel courses at the company's Renfrew works.

principle ones being as follows.

Within the present-day limitations of theoretical stress analysis techniques, the state of local stress associated with the junction of the support with the reactor vessel can be predicted with much greater reliability for a continuous skirt support than for a system of discreet point supports. This statement remains true even if resort is made to experimental investigations of models, since it is not possible to reproduce in a model test all the factors which would contribute under operating conditions to the stress system existing in these regions.

A system of individual point supports usually allows for the thermal expansion and pressure inflation of the vessel by the incorporation of

rolling or sliding surfaces. It was felt that, since these features would be located in an area where radiation levels would make access for maintenance and inspection impossible during the operating life of the plant, the continuous skirt support was to be preferred since in this solution no sliding or rolling surfaces were involved and the thermal expansion and pressure inflation of the vessel were accommodated by the inherent flexibility of the cylindrical skirts.

In a discreet, multi-point support system it is possible to visualise circumstances under which, due to uneven resistance to sliding or rolling at the various support points, as a result of repetitive pressurisation and depressurisation and heating and cooling

cycles, the vessel might move during the lifetime of the plant. By comparison the continuous skirt support offers the advantages of a self-centralising design.

The attachment of individual support brackets to a reactor vessel is usually directly, or indirectly, by means of fillet welds, which on a general quality expectation do not compare favourably with double butt-welds normally used in cases where consistently high quality of weld is required. In the case of the Hinkley Point reactor vessels the junction between the continuous internal and external skirts and the two parts of the reactor sphere meeting at this intersection has been achieved through the incorporation of a special forged ring of cruciform section to which the above four components are attached by means of double butt-welds. In this way the attachment welds between the support members and the reactor shell can be made to a standard consistent with best practice for pressure vessels and, in addition, can on completion be examined by radiographic means similar to those used for the plate seams of the reactor shell proper.

The main outlet and inlet gas nozzles are of forged construction and, in common with other reactor designs at present under construction, incorporate a continuous lip on the outside of the forging of the same thickness as the adjacent reactor plates, so that the attachment weld between this nozzle and the reactor plate can be made by double butt-welds capable of radiographic examination.

Construction of top dome

The problems associated with the design, construction and inspection of the top dome of the reactor vessel containing the large number of nozzles for charge and discharge and control rod standpipes offer substantial scope for ingenuity. Adequate compensation must be provided in accordance with the requirements of the relevant codes of practice for the openings cut in this area of the vessel on a fairly close pitch. The attachment welds between these nozzles and the reactor shell must be so designed as to provide adequate strength to make the reinforcement contained in the nozzles effective, whilst giving good access during welding and keeping the total amount of weld metal deposited to a minimum. Since the cutting of the holes in the reactor vessel and the welding-in of the nozzles are both carried out at site, a number of special-purpose portable machines have been developed by Babcock & Wilcox Ltd. for the cutting of the holes and the machining of the weld preparations. The capabilities and limitations of the weld preparation machine clearly govern to a large extent the solutions of the welding access problems and the total amount of weld metal which has to be deposited.

Alignment tolerances

The charge/discharge and control rod standpipes and nozzles are subject to alignment tolerances which are not commonly encountered in the case of pressure vessels of comparable size outside the nuclear field. The particular design solutions and manufacturing techniques chosen for this reactor vessel enable these tolerances to be met without recourse to such obvious but extremely laborious and costly operations as for instance the boring out of each nozzle and standpipe *in situ* after completion of fabrication of the reactor vessel.

It is appropriate to point out that satisfactory economic solutions to such problems can only be achieved by intimate, day-to-day collaboration between all the sections of an organisation responsible for the design, works manufacture, welding development, erection and inspection of such components. The magnitude of such problems in addition can be substantially reduced at the very conception of the design where proper liaison exists between the engineers responsible for the design of the pressure vessel and those concerned with the design of the reactor core and the charge equipment.

Method of transportation

All the reactor pressure vessels at present under construction for the Stage 1 nuclear power station are far too large to be transported to the construction site other than in relatively small sections. Considerable differences in policy between the various construction organisations at present building such vessels appear to exist regarding the proportionate distribution of the amount of work to be carried out at the works and at site.

The freedom of choice in this respect is undoubtedly governed to a large extent by the location of the particular site and by the means of transport available for the shipment of the components from the works. It is probably influenced in addition by the sheer size of works, the capacity of permanent plant at works, and by the experience and tradition of the particular organisation involved. In the case of the Hinkley Point reactor pressure vessels, it was decided to take full advantage of the ability to transport from the works to site by sea, in carrying out at the company's works the greatest possible amount of prefabrication of the largest transportable sections consistent with the requirements of the overall station construction programme. This latter aspect is of primary importance and it is likely to influence not only the decision as to how much fabrication to carry out at the works, but may also prove the deciding factor with regard to the erecting methods at site, and to the split-up between work in fabrication shops at site against work *in situ.*

In the case of the Hinkley Point reactors, the close collaboration in the preparation of the overall station construction programme in particular between the civil contractor and the pressure vessel contractor has enabled a substantial amount of site work to be carried out in prefabrication shops, thus avoiding interference between these two aspects of construction work, which of necessity must proceed simultaneously. Thus complete ring sections of the reactor vessels have been constructed in the prefabrication shops and lifted as a whole into the biological shield by the 400-tons-capacity *Goliath* crane built by Babcock & Wilcox Ltd. specifically for the construction of the Hinkley Point station (see Fig. 5).

Dimensional accuracy

Another aspect of construction of reactor vessels in which a considerable divergence of approach can be noted between the various organisations engaged in such constructions at present is the question of the methods employed to achieve the required dimensional accuracy of the finished vessels. One method appears to be that of producing individual plates or plate assemblies at works to roughly correct dimensions and then making the final corrections during assembly at site by making adjustments to oversize plates provided specially for this purpose. Similar adjustment is known to be made at site to the matching weld preparations, between successive rings of the pressure vessel. A totally different policy was decided upon in the case of the Hinkley Point reactor vessels. The plate assemblies shipped from the works have been manufactured with such dimensional accuracy that no significant adjustment at site has been necessary, thus obviating the need for providing template pieces.

The standards of workmanship and in particular the standards of welding required for the Stage 1 reactor pressure vessels are high, for obvious reasons, but are in no way significantly higher than those achieved by competent pressure vessel fabricators for many years outside the nuclear power field. In view of the recent publications of statements regarding the difficulties experienced in achieving these standards, it may be appropriate to suggest that such difficulties might be attributable to the lack of relevant experience on the part of the organisation involved. Thus it can be seen that, although there exist some significant differences between nuclear and conventional pressure vessels, these are no greater than the differences between pressure vessel characteristics in two different fields of conventional utilisation.

Acknowledgments

Vacuum flash evaporators

The Richardsons Westgarth Group have received an order worth nearly £500,000 from the Government of Qatar for two multi-stage vacuum flash evaporators each having an output of 750,000 gal./day of fresh water.

The two new evaporators will be installed at the new Ras Abu Aboud power station and will operate on low-pressure steam from pass-out turbo alternator sets. They will provide high-purity water at very low cost for both domestic and boiler feed purposes.

Processing of Nuclear Fuels

SAFETY CONSIDERATIONS IN DESIGN

By C. Hanson,* B.Sc., Ph.D., A.R.I.C., A.M.Inst.F.

The fatal incident at Los Alamos showed the dangers inherent during manufacture and reprocessing of nuclear fuels. Prevention of all criticality incidents is an important criterion that must be taken into account by chemical engineers when designing such plant—especially since, with the development of fast reactors, even larger quantities of fissile material will have to be processed. This article surveys several current methods of criticality control and discusses their limitations.

DURING the manufacture and reprocessing of nuclear fuels, it is necessary to handle considerable amounts of fissile materials, such as uranium-235 and plutonium-239. If these are allowed to accumulate in sufficient quantity, then under suitable conditions a fission chain reaction can be initiated which will lead to the evolution of heat and a dangerous neutron flash. The reality of this danger is emphasised by the reports of the fatal accident at the Los Alamos plant in the United States.[1] The necessity of preventing such criticality incidents presents the chemical engineer with a novel and extremely important design criterion.

The violence of these chain reactions is governed by a number of factors such as the quantity of fissile material present, the speed with which critical conditions are approached, the conditions of containment, etc., and, depending upon these, the result could vary from a violent explosion to a very mild excursion. Any explosion would only be of ' conventional ' magnitude and not comparable with an atomic bomb. However, it could cause extensive damage to the plant, the repair of which would be seriously hampered by heavy contamination with fission products. This could in turn lead to the shutting down of any reactors dependent upon the plant concerned. In addition, an explosion could conceivably rupture the shielding surrounding the plant, depending on its form, and this could lead to the dissipation of dangerous fission products over a considerable area. Whilst undoubtedly important, the explosion aspect of an incident should not be over-emphasised. American experience suggests that the principal

hazard is from the associated radiation emission. It appears that criticality incidents in chemical plants are likely to be of a relatively mild form and that, in fact, it is quite possible for there to be no visible indication of the accident. In such an eventuality, unless warning instruments are provided, personnel could unknowingly remain in a dangerous area for a long period and so receive high doses of radiation.

It is clear from the above points that the prevention of a criticality incident is an imperative consideration which must be recognised from the original conception to the final operation of any plant handling fissile material, although it is probable that the inherent safety of a plant is governed mainly by the decisions taken at the design stage.

Methods of criticality control

The possibility of a criticality incident during the processing of fissile material can, in general, be avoided either by limiting the mass of the fissile material present, by preventing its concentration rising above a safe level, or by the use of geometrically safe equipment.

In the fission process, more neutrons are produced than are responsible for initiating the reaction. Some of these are lost from the system, but if more than one is available to cause further fission, a chain reaction will result and the system will become critical. The methods of criticality control are therefore designed to ensure that the neutron loss from the system is sufficient to prevent this chain reaction.

For any particular set of conditions, there is a certain critical mass of fissile material below which it is impossible

for the chain reaction to be sustained. Its actual value depends on the material involved, its concentration, the geometry of the system, and the presence of neutron moderators, reflectors and absorbers. In Table 1 are listed the minimum critical masses for fully water-reflected, water-moderated systems of optimum concentration and geometry.

Table I. Minimum critical mass[2]

				Grammes
U^{235}★	..	..	..	780
Pu^{239}	..	..	..	464

★About 90% U^{235} + 10% U^{238}

This obviously provides one possible method of criticality control, *i.e.* to ensure that no more than the minimum critical mass of the fissile material is present in the system at any time. Whilst this is a perfectly satisfactory method, especially when refined by the application of safety factors to allow for accidental batch doubling, etc., its use is normally restricted to laboratory or very small-scale processes owing to the small weights of material allowed.

Geometrical limitation

Neutrons escape from the surface of the vessel containing the fissile material and, therefore, by using a geometrical shape with a high surface area-to-volume ratio, it is possible to ensure that the neutron leakage is of such magnitude that it is impossible for the chain reaction to be sustained. Thus, for each fissile material, there are minimum critical dimensions.

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The magnitudes of these again depend on the concentration of fissile material and the presence of neutron moderators, reflectors and absorbers. Typical values are given in Table 2 for critical, water-reflected solutions of optimum concentration.

Table 2
Minimum critical dimensions[2]

Fissile material	Sphere diam. (in.)	Cylinder diam. (in.)	Slab thickness (in.)
U²³⁵★	8.5	6.0	1.9
Pu²³⁹	8.0	5.1	1.6

★Approximately 90% U²³⁵ + 10% U²³⁸

This gives a second method of providing criticality control, and one of fairly wide application. It is the one generally chosen for plants processing highly enriched material as the throughputs are then usually fairly low. The question of throughput, however, is the main limitation of this method, as it is often difficult or impossible to design equipment using these restricted dimensions which will give the throughputs required.

Concentration limitation

The third method of preventing criticality incidents is to ensure that the concentrations of fissile material in the system do not exceed a safe value. Just as there are minimum critical masses and dimensions, so there are minimum critical concentrations. These are given in Table 3.

Table 3
Minimum critical concentrations[2]

				g./l.
U²³⁵★	..	..	..	11.0
Pu²³⁹	..	..	..	6.6

★Approximately 90% U²³⁵ + 10% U²³⁸

In general, concentration limitation is the method most readily applied to plants handling high throughputs of low-enrichment material. In such cases guarantees must be provided against any accidental increase in the concentrations above their design values.

Certain reservations must be placed on the minimum critical conditions specified in Tables 1, 2 and 3. The plant must be isolated from other sources of neutrons. No reflectors more efficient than water are assumed and the fissile material must be dispersed homogeneously throughout the system. Finally, the temperature in aqueous systems must not be substantially below 20°C. In addition, these parameters give what could, in
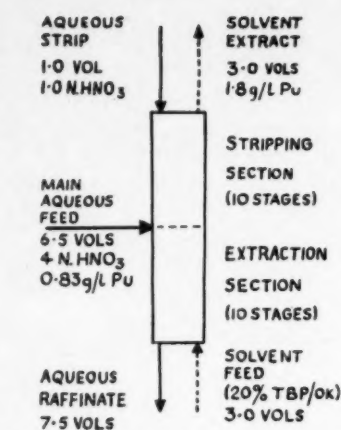

Fig. I. Typical solvent extraction system.

the worst case, be critical conditions. Hence, for plant design purposes, safety factors would normally be applied to them.

Discussion

Criticality control by mass limitation is clearly of very limited applicability and is certainly not suitable for high throughput plants.

Concentration limitation is the method most generally applied to plants handling high throughputs of fissile material at relatively low concentrations. The flowsheets for the process are prepared so that the concentrations of fissile material at no point exceed a safe value. Chemical and chemical engineering assurances must then be provided against dangerous accidental increases in concentration as a result of mal-operations. This is one inherent difference between the concentration limitation method and the mass and geometric limitation methods. Thus it is recognised that serious mal-operation could cause a criticality incident.

Detailed consideration must be given to the effects of variations, both separately and together, of all the process variables, to the extent of any resulting build-up of fissile material, and to the possible rates of accumulation. On the basis of this information, instrumentation can be designed to detect a tendency towards, and so to prevent, any dangerous accumulation. If the throughput of fissile material is sufficiently small, an additional safeguard can be achieved by accountancy. Thus the quantities of fissile material entering and leaving the plant can be carefully monitored and the plant closed down for inspection and washout whenever the difference between the amount of material which has

entered and left exceeds the minimum critical mass. This is obviously limited to plants where the throughput is sufficiently low for analytical results to be available before a critical mass could accidentally accumulate.

Solvent extraction

Perhaps the most important unit operation in the processing of nuclear fuels is solvent extraction and this provides an excellent example of the general method of approach in the application of concentration limitation. Consider the typical solvent extraction contactor shown in Fig. 1. In this a fissile material, plutonium, is extracted from an aqueous feed into an organic solvent. The contactor consists of two parts, the extraction section and the stripping section. In the former the plutonium is extracted from the aqueous stream into the organic phase, whilst in the stripping section the solution of plutonium in the organic solvent is washed with a suitable aqueous solution to remove any impurities which were carried over into the organic phase in the extraction section.

The maximum concentration of plutonium within such a contactor can easily exceed the feed and extract concentrations. It is therefore necessary to calculate the concentrations of plutonium in the conjugate phases at each stage within the contactor. These can be obtained by means of a Fenske-type diagram[3] as illustrated in Fig. 2. The gradient of the operating line for any stage is the aqueous/solvent flow
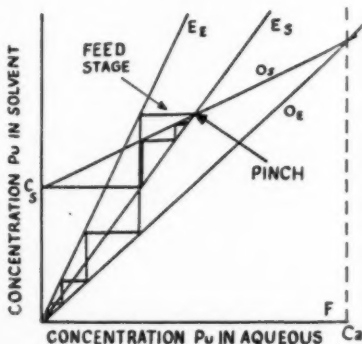

Fig. 2. Typical equilibrium diagram:

C_s = Concentration Pu in solvent extract

C_a = Concentration Pu in main aqueous feed

E_e = Equilibrium line, extraction section

E_s = Equilibrium line, stripping section

O_e = Operating line, extraction section

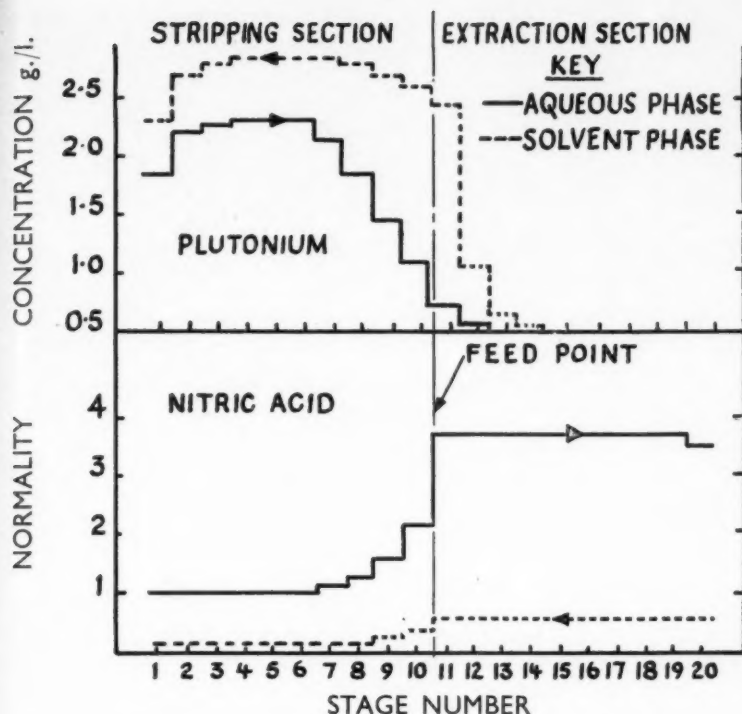O_s = Operating line, stripping section

Fig. 3. Concentration profiles for system shown in Fig. 1.

measurements. In addition, the concentrations within the contactor may reach a dangerous value without there being any loss in the aqueous raffinate. It would obviously be possible to guarantee the safety of the contactor by measuring the plutonium concentration in each phase of every stage. This, however, would require a very large number of instruments, would greatly complicate the general process control of the plant, could lead to many false alarms and shut-downs, and would be extremely expensive. This problem can be overcome by use of the ' sensitive point ' concept. Thus instrumentation can be provided on the appropriate phase at the most sensitive points within the contactors, as shown by the concentration profiles, to detect any accumulation of fissile material.

The accumulation of dangerous concentrations of fissile material in solution within the contactors is only one aspect of the criticality problem within such a plant. It is also possible for dangerous amounts of plutonium to collect on cruds and sludges within the contactors. It is important to ensure that there is no possibility of plutonium being precipitated and allowed to build up at any point in the process. Such a position could occur, for example, if plutonium was hydrolysed at any point due to the acidity being allowed to fall too low or to considerable rises in temperature.[4] This hazard is obviously associated with backwash contactors, but it may also arise at other points due to accidental water dilution or overheating, for example in pumps. Such possibilities must be obviated in the design of the plant. Certain items of plant may require periodic washing out to remove any sludge which may have collected and which may contain fissile material.

The concentration limitation method is ideally suited to plants processing fuels with only a low fissile material content, e.g. irradiated fuel from the C.E.G.B. stations at present under construction. However, with more advanced types of reactors the fissile material content will be too great for it to be applied. In such cases the use of geometrically limited plant is the only possible method. Up to the present time, advanced types of reactors such as fast reactors have only been operated on an experimental scale. As a result, the amounts of fuel processed have been small and little difficulty has been reported in the design of suitable geometrically limited plant.[5] However, as such reactors are

ratio whilst the gradient of the equilibrium line is the distribution coefficient for the component considered under the conditions of that stage. This gives the concentration profile for plutonium within the contactor. The profile for the case illustrated in Fig. 1 is shown in Fig. 3.

The stability of such a system is dependent entirely on the acidities and flow rates of the various feeds. Increase in the concentration of the fissile material within the contactor could be caused by a decrease in the acidity of either the aqueous strip or the main feed, or by an increase in the aqueous/solvent flow ratio in any section of the contactor. Decrease in the aqueous acidity decreases the slope of the equilibrium line and hence moves the ' pinch point ' to higher concentrations, whilst increase in the aqueous/solvent flow ratio increases the gradient of the operating line with the same result. For efficient extraction, it is essential that at every stage the gradient of the equilibrium line should be greater than that of the appropriate operating line. Mal-operation of the feeds will usually lead to peaks of plutonium concentration within the contactor and, possibly, to loss of plutonium in the aqueous raffinate. By calculating the concentration pro-

files for a series of mal-operations, it is possible to specify approximately the positions of these peaks. These are sensitive points for the accumulation of plutonium within the contactor and a knowledge of their positions is of the greatest importance when designing the instrumentation to safeguard against criticality.

Control of feed

Assuming the flowsheet to be properly designed, then, provided complete chemical and chemical engineering assurances on the behaviour of the equipment could be given, it would, in theory, only be necessary to control the quantity and quality of the feeds. Whilst every effort should be made to provide perfect control of all feeds, it is nevertheless impossible to guarantee absolutely the behaviour and safety of the plant on this alone. Instrumentation on the raffinate streams is important for safeguarding ancillary equipment such as associated effluent treatment plants and will, at the same time, give some warning of mal-operation of the main extractor. However, the residence times within the contactor may be so long, compared with the minimum time for the accumulation of a critical mass, that very much reliance cannot be placed on terminal

DRYING

CPE *Chemical Engineering Review*

By W. F. Calus,* M.Sc.(Lwow), D.L.C., A.M.I.Chem.E.

The annual review of new developments in the theory and application of drying, surveys the literature up to the middle of this year— there are about the same number of contributions to fundamental research in drying as in previous years. A significant factor in this field has been the considerable developments in drying techniques, no doubt prompted by the necessity of drying new materials for which conventional driers are unsuitable. Fluidised-bed techniques, acoustic drying and dielectric heat drying are notable examples of these new techniques which are comprehensively reviewed.

Fig. I. Air drier used on this ship is a ' Birlec ' model C.R. dehumidifier.

THE literature on the technology of drying gained two major contributions in the form of two valuable books treating scientific principles and practice to an even larger extent than is the case with other chemical engineering operations. The second volume of the work by Krischer and Kröll on the technology of drying is now available. The first volume published in 1956 is devoted entirely to the scientific principles of drying and contains a very comprehensive treatment of heat transfer, mass transfer, mechanism of drying of various types of materials and even a chapter on the methods of moisture determination in the materials and the drying media. The subject of the second volume is a 560-page discussion of the various types of drying equipment from the standpoint of the designer, and the problem of the properties of the material to be dried and the choice of a suitable type of drier is given sufficient attention.[1]

The book ' Das Trocknen ' by F. Kneule[2] covers the theoretical and practical aspects of the whole field of industrial drying. A detailed treatment of such topics as diffusion, adsorption, capillarity, heat transfer and mass transfer forms the theoretical background of the large section devoted to the description of the industrially important types of driers and the analysis of their performance in the light of these basic principles. Laboratory drying apparatus and equipment for small-scale industrial applications are also treated. The summary of the various methods of psychrometric measurements and a large collection of design data add to the completeness of the treatment of this branch of technology. This book is Volume VI of the series ' Grundlagen der Chemischen Technik '.

As the pneumatic type of drier is becoming an established method of drying, a knowledge of the more basic problem of pneumatic conveying is relevant. Bannister[3, 4] provides a review of the scientific literature on pneumatic systems and of empirical knowledge of them.

Fundamental studies

The residence-time distribution and flow pattern of the air in a full-scale industrial spray drier were investigated, using the tracer technique, and simulated by experiments on a one-eightieth-scale model in which the fluid used was water.[5] Strict dynamical similarity was not achieved with the flow rates which were practicable for the model, the Reynolds number being only about $\frac{1}{20}$ of that on the full-scale plant. The lack of complete dynamic similarity would not affect the general nature of the flow pattern, according to an earlier work quoted by the authors.[6] Both in the drier and the model the fluids were fed by a swirling-type motion which is responsible for a zone of reversed flow, causing some amount of back-mixing.

The velocity survey and the model experiments indicate the existence of an isolated core of air, with a high vertical velocity, channelling along the axis of the drier. This has not been

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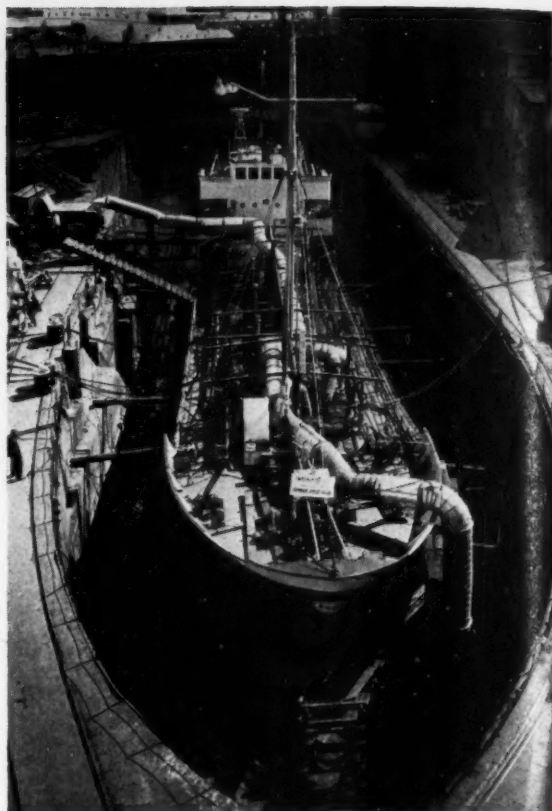
confirmed by the tracer experiments or temperature survey, however, but on balance the authors are inclined to believe that the core exists.

Nissan *et al.* continued investigation into the mechanism of drying thick, porous bodies during the falling-rate period. Two materials of widely differing pore structure—*Terylene* net fabric of open structure and a woollen flannel of close structure—were used. Test samples, consisting of fabric wound on a spindle forming an annular package, were placed in a current of hot air.

In their first contribution[7] they established the existence of a similar equilibrium between heat transfer inward and vapour diffusion outward at a constant pseudo wet-bulb temperature during the second falling-rate period, despite the difference in the structure of the materials. They also found that the apparent thermal conductivity of the dry *Terylene* bobbin increased near the surface, while that of the wool was constant throughout the whole depth. The difference is most likely due to turbulence created by the passage of air over the rough surface and penetrating to an appreci-

Fig. 2. 'Newstadt' rotary sand drier and cooler supplied by Modern Furnaces and Stoves Ltd.

able depth in the case of the *Terylene* with large pores and to a negligible depth in the case of the wool with fine pores. The hygroscopic nature of the wool was ignored in that work and therefore their second contribution[8] analyses further the data given previously for the wool, taking into account the adsorbed water. The values of the apparent thermal conductivity of the wet wool were calculated and were found to increase with the free water content. The authors suggest rightly that similar investigation should be carried out on materials other than textile fibres to find whether the pseudo wet-bulb temperature is a general phenomenon.

Dlouhy and Gauvin[9] investigated heat and mass transfer in a concurrent spray drier 8 in. diam. and 14 ft. high and found that their experimental time for drying a spray agreed with that calculated by a step-by-step method. The heat and mass transfer computations were based on the equations recommended by Ranz and Marshall.[10] The feed to the drier was an 18% solution of calcium ligno-sulphonate in water and the authors are of the opinion that the method would be applicable to other materials of similarly high solubility.

A sample of the same feed was also subjected to tray-drying and it was noted that the falling-rate period was appreciable, in marked contrast to the spray-drying experiment. This difference is ascribed to an earlier formation of a heavier crust which increases the diffusional resistance to evaporation of water in tray-drying.

Evaporation from drops

Charlesworth and Marshall[11] studied the evaporation from single drops containing dissolved solids, and developed a formula for predicting the time required for the appearance of a solid phase on the droplet surface and also for the completion of the crust. The time required to reach this latter stage is called 'the first period of drying' and their formula gives values agreeing within $\pm 15\%$ of those obtained empirically on an appreciable number of inorganic salts in water. The correlation was first derived by means of a mathematical analysis of the problem, assuming an idealised behaviour of the droplet, *i.e.* spherical symmetry in and around it, lack of solute circulation, etc. The empirical evidence justified further simplification of the complicated theoretical expression, so that for a numerical solution only the knowledge of the evaporation

constant for a given system is necessary, apart from the common physical properties. The final dried particle was not always spherical and the decrease in the volume of the particles from initial droplet to dried particle, when drying below the boiling point, was equal to the volume of the water evaporated before the completion of the solid crust. For drying at temperatures above the boiling point no generalisation is suggested, but in many cases the final particle was larger than the original droplet because of inflation of the crust by internal pressure.

Drying rates in 'the second period of drying', *i.e.* from the completion of the crust till the removal of the remainder of the free water, showed so much variation from particle to particle that, although they were dried under identical conditions, a qualitative analysis of the results is impossible. An illustration of the application of the results to a spray-drier performance is given. Rühle[12] measured the heat and mass transfer to calcium carbonate and polystyrene spheres conveyed by a stream of hot air up a vertical tube. The values of the local heat- and mass-transfer coefficients are based on the surface area of the particles and show agreement with similar data obtained by other workers. It was found that the heat-transfer coefficient increased by about 30% for an increase in air velocity from 10 to 20 m./sec. in the zone of steady flow. The increase is
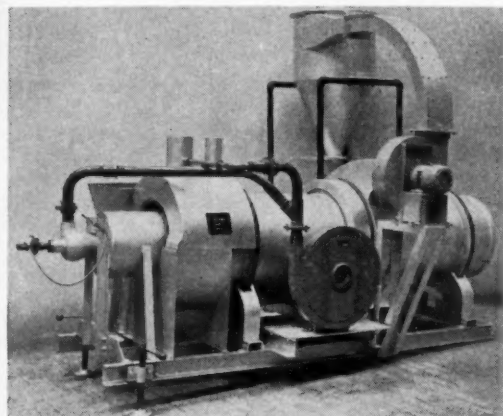

Fig. 3. Medium size Mitchell 'Ventil' continuous pneumatic drier by L. A. Mitchell Ltd.

due to the larger turbulence around the particles at a higher air velocity. The difference between the air and particle velocities was proved to be constant in that zone irrespective of the air flow rates. In terms of H.T.U. for heat transfer a higher tube would be required with higher velocities for transferring the same quantity of heat when working at the top value of solids loading.

The weight ratio of calcium carbonate to air ranged from 0.13 to 0.5 and it had no effect on the magnitude of the heat-transfer coefficient. Much higher transfer rates were proved to exist at any small distance (up to 3 ft.) from the solids feeding point where the particles were being accelerated to their constant velocity relative to that of the conveying air. The particles were wetted with water for mass-transfer investigations and the observations made are apparently the same as in the heat-transfer experiments. The author points out quite rightly that a pneumatic conveyor drier, to be efficient, should either be operated by recirculating a large proportion of the solids or should be designed as a multistage plant. This paper gives 47 literature references.

Very closely related to drying problems is the work of Pearce and Donald.[13] By considering energy changes they have studied the relationship between suction and shrinkage forces in porous substances of widely differing configurations and moisture contents. Knowledge of drop-size distribution is of the utmost importance in spray drying. The work of Dombrowski and others[14] leads to the solution of the problem. They have investigated the flow pattern of the liquid sheet produced from rectangular-orifice fan spray nozzles with special emphasis on the manner in which its thickness varies from the orifice to the point of breakdown.

New drying techniques

The vortex-impulse drier is a recently developed drier reminding one of a fluidised-bed apparatus. The plant is recommended for drying bulk materials, water or solvent wet; two types are described and some performance data are given by Belik.[15] In this drier, hot air is admitted through four or five distributors located on the walls of a conical bottom. Only one air distributor is operated at a time and the air rate is much smaller than in a fluidised bed and so is the expansion of the material in it. The rotational system of feeding the drying gas makes formation of channels or blow-

holes in the bed impossible, thus ensuring even distribution of the drying medium throughout the mass of material. The amount of movement of particles relative to one another is small and consequently the abrasion effect is negligible.

In the case of abrasion-sensitive particles where even small amounts of movement are damaging, a superimposed vortex-impulse drier is used. This has, in addition to the impulse gas supply, a continuous gas supply small enough not to cause any vibration of the particles. The impulse gas is used periodically (e.g. one impulse every 6 min.) in order to destroy any channelling or blowholes that might have developed. As a rule the second type (and sometimes the first type) must be fitted with heating jackets to supplement the heat supply. The driers of this type also incorporate a bag filter kept at the required temperature by means of heating jackets.

Acoustic drying

Boucher[16] presented results on drying a number of materials in a pilot-plant acoustic drier and listed the factors relevant to this technique, and in a few cases compared the results of acoustic drying with those of conventional thermal methods. A high-intensity acoustic field, just above a liquid surface or above a liquid-coated material, produces violent surface cavitation and consequently a continuous surface renewal. This, together with a partial vacuum or a strong current of air carrying away the water vapour, satisfies the basic requirements of an

acoustic drier. In the case of drying bulky materials a continuous mixing (such as is produced in a rotary drier) is also necessary. Compressed-air-powered jets were used to generate the high-intensity acoustic field in these experiments.

The following operating conditions for good drying results were established:

(1) Sound intensity level should be not less than 145 decibels.
(2) Thinner material layers dry faster and the maximum thickness suggested is 1 to 2 in.
(3) Optimum frequency range is 6 to 10 kc/sec.
(4) Highly turbulent flow of the gas above the treated material is of the utmost importance.

Acoustic drying can be carried out in the apparatus used for some thermal methods of drying, e.g. spray driers or rotary driers.

Results of conventional spray drying are compared with those of acoustic drying in the same spray drier and with respect to the same material. It appears that in the latter the proportion of the smallest particles was appreciably reduced due to some agglomeration taking place. Comparison of the time of desorption of silica gel by various conventional methods and by acoustic drying is given, showing a distinct superiority of the latter. As acoustic drying can be carried out at any temperature, its application to heat-sensitive materials is most appropriate. The presentation of this method would have been more complete if the author had compared
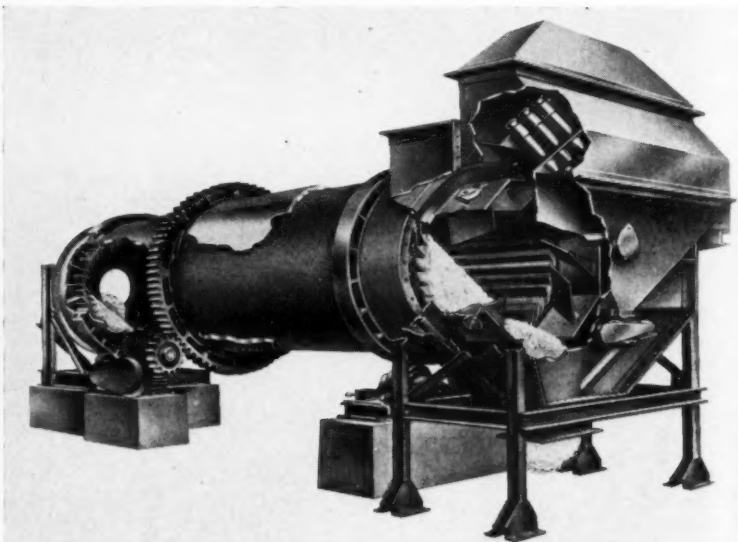

Fig. 4. Rotary louvre of Dunford & Elliot Process Engineering.

the costs of drying by this method and by some conventional thermal driers.

Reference 17 describes the 'Thermatool dielectric drier', manufactured by New Rochelle Tool Co., N.Y., and gives its performance data. The latter refer to drying rayon synthetic fibre as compared with that of previously used conventional driers. The advantages of this drier lie in a very drastic reduction in the time of drying, and also in some reduction in the operating costs.

Grant and Ward have described large-scale laboratory freeze-drying apparatus which was constructed to their design. Performance data are given.[18]

A special vacuum plant for freeze-drying of streptomycin constructed by Edwards High Vacuum Ltd. is described in reference 19, where 300 l. of streptomycin salt is dried to a moisture content of 1.5% in 22 hr.

Modified drying equipment

The superior adsorbing properties and performance of ' molecular sieves ' as compared with activated alumina in drying hydrogen-rich gas from platinum reformers at Sun Oil Co. are described by Cochrane.[20] Molecular sieves have uniform pore sizes, allowing them to adsorb molecules of a certain size while completely rejecting larger molecules. For example, they adsorb water while rejecting aromatics and branch-chained and larger hydrocarbon molecules. Water capacity of the molecular sieves is about five times greater than that of activated alumina while the cost is only about four times as much. Although molecular sieves greatly increase the capacity of driers, they have almost no effect on the dewpoint of the effluent gas.

The rotary louvre drier of Dunford & Elliott Process Engineering Ltd.[21] has been adapted to the drying and cooling of very fine materials by altering the method of heat transfer. Heating by convection is replaced by conductive heat transfer, thereby eliminating the flow of gas through the bed of material. When heating, a flame, or alternatively hot air, is applied directly to the number of louvres, which in turn rapidly transfer their heat to the material. When cooling, sections of the louvres cooled by air successively extract the heat from the hot material. If necessary, a small volume of the gas may be passed through the bed at a velocity to suit the fineness of the material being processed without risk of losing any significant amount of fines. The effectiveness of the modified drier was shown on black iron

Fig. 5. Fluidised bed type drier for granular solids made by Aeromatic A.G.
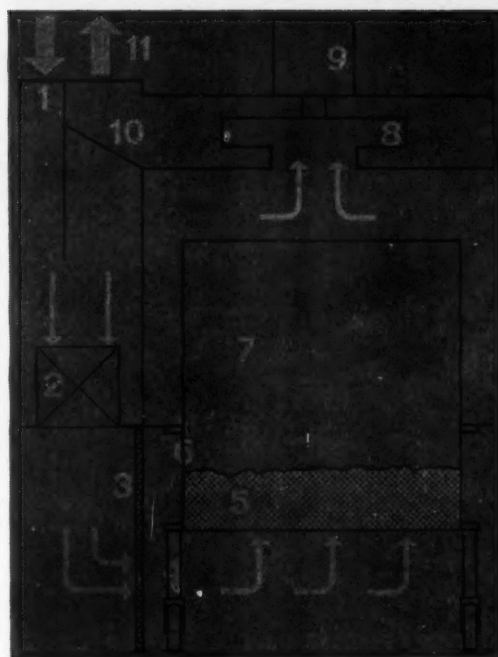
oxide filter cake and a catalyst based on diatomaceous earth in very fine powder form (see Fig. 4).

Fluidised-bed techniques

Increased use of fluidised-bed techniques for drying is reported from the United States,[22] where coal is being dried in units of up to 14 ft. diam. which handle up to 800 tons/hr. of coal, and rotary kiln driers are being replaced by fluid-bed driers.

A Swiss firm, Aeromatic A.G.,[23] manufacturing fluidised-bed-type batch driers recommends them for drying fine chemicals and pharmaceuticals as well as food products of granular structure. In accordance with the character of these materials the plant is small and ranges in capacity from 11 to 440 lb. (see Fig. 5).

Descriptions and constructional and operating features of a whole series of solid-desiccant-type driers for air and other gases, together with selection charts, are published in a comprehensive brochure by W. C. Holmes & Co. Ltd.[24]

An improved design of the Newstad rotary sand drier is being manufactured by Modern Furnaces & Stoves Ltd.[25] The drier consists of two sections, one drying the sand by conduction heat transfer and the second cooling the dried sand by direct contact with an air stream (see Fig. 2).

The Mitchell Ventil drier[26] is a pneumatic-type drier. The operation of it involves recirculation of a controlled quantity of hot air and material.

The manufacturers claim uniformity of the resulting product and high thermal efficiency due to the high recirculation ratio (see Fig 3).

The features of a patented spray drier[27] for drying milk are described and the operating conditions broadly outlined in reference 28. The resulting product is a coarse powder having good dispersability.

Revised drying conditions in a rice drier and the resulting increase in the capacity of the apparatus and improvement in the quality of the product are given in reference 29.

Adsorber-type driers are manufactured by G. W. B. Furnaces Ltd.[30] These are designed to maintain a constant low-level moisture content in the gas stream. Their capacities range from 20 cu.ft./min. upwards.

Another adsorber-type drier of pilot-scale size is manufactured by Birlec Ltd.[31] The plant was designed to dry air and gases for atomic energy pilot plant, furnace atmosphere dewpoint control, stainless-steel brazing and similar duties. The desiccants used are activated alumina, molecular sieve adsorbent, silica gel or aluminium silicate, depending on the duty of the plant.

The work of reconditioning the interior surfaces of ships' hulls and holds requires a salt-free and dry atmosphere. It is for the first time that this kind of atmosphere has been ensured in a British dockyard—by a large, industrial, air drier on the tanker

Esso Hermod. The air drier used was a *Birlec* model CR dehumidifier[32] of 2,000-cu.ft./min. capacity (see Fig. 1).

The more recently developed or improved designs of drying equipment are reviewed and some of them described in detail by Lomas.[33] The author lists the firms manufacturing this equipment and also the materials which were successfully dried in these types of driers. This review is particularly useful for those seeking a suitable drier to solve their particular problem. The types described are: film driers, vacuum driers, vacuum shelf driers, drum driers, spray and pneumatic driers.

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Equivalent Lengths of Pipe Fittings

By D. S. Davis*
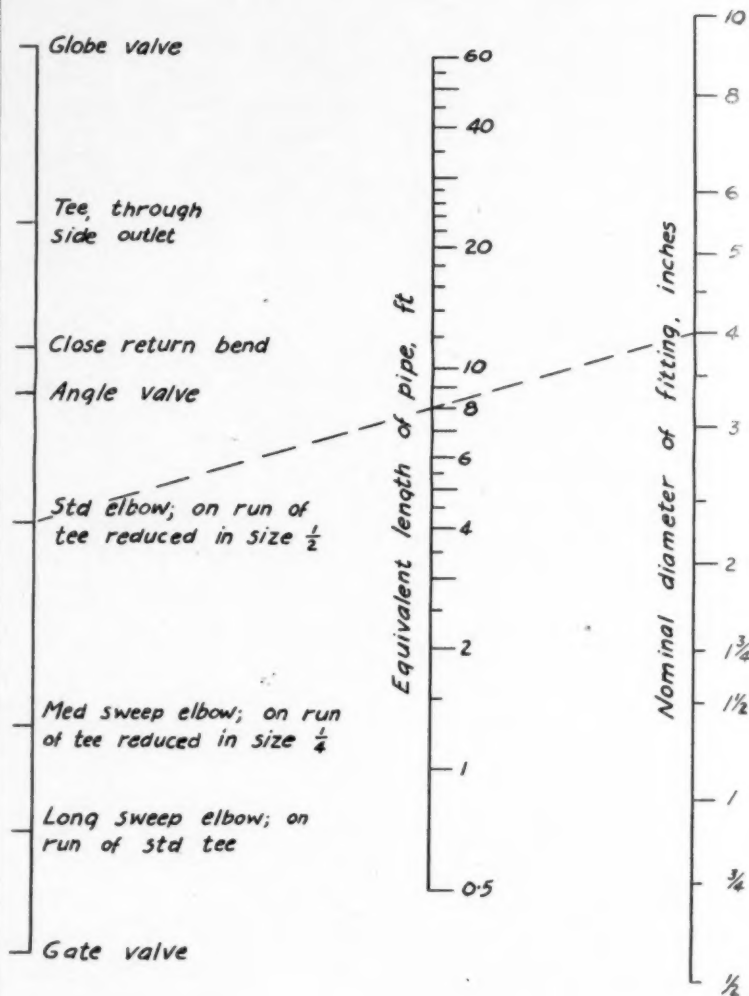
In computing pressure drops in pipelines it is customary to allow a certain length of straight, standard pipe for each valve, elbow or other fitting. Equivalent lengths, L, in feet, depend upon the diameter of the fitting, d, in feet, in accordance with the equation[1]

$$L = 43.7 \, r \, d^{1.2}$$

where r is specific to the fitting.

The accompanying nomograph en-

ables one to determine equivalent length quickly and accurately. The broken index line shows that a 4-in. standard elbow offers the same resistance to the flow of the fluid as do 8 ft. of 4-in. pipe.

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Chemical Engineering Fundamentals – 3

By K. L. Butcher,* B.Sc., F.R.I.C., M.I.Chem.E.

In his third article in this series, undertaken to re-examine some principles fundamental to chemical engineering, the author derives the first law of thermodynamics and discusses the concepts of total energy, enthalpy and its relation to specific heat. By discussion of reversible and irreversible conversion of heat into work, the concept of entropy is introduced and its relation to the second law of thermodynamics is postulated. Finally, an estimation of changes in entropy due to mixing of gases is given.

IN article 2 an outline of the kinetic theory of gases led to an attempt to account for the energy of a given amount of 'stationary' gas in terms of the energy of the random motion of the molecules. In the case of a perfect gas this would be a satisfactory method of accounting for the thermal energy of the gas molecules. For real substances not only the motion of the molecules but their relative position to one another is important (through their mutual potential energy). For the perfect gas it is presumed that molecular motion ceases at 0°K. This is true of translational motion—but not so of rotational and vibrational motion.

Obviously once the molecules have been brought to a standstill in space, there is no mechanism apart from 'radiation' by means of which they can transfer energy to one another or their surroundings. At the absolute zero of temperature a molecule obviously has inherent energy possessed by its atoms which in turn have the inherent energy of the constituent protons, neutrons and electrons, etc. These inherent energies are, of course, different from those possessed by the atoms, protons, etc., in the 'free' state. Therefore the total energy content of a substance at 0°K. may be denoted E_o/g.mol. and this will be called the internal energy. This may be increased, without chemically changing the substance, by adding heat (dq) or by doing work on the substance. By work in this context is meant direct mechanical effort, *i.e.* force × distance and in the case of a gas at pressure p, if made to change by volume dV (dV is a negative number for a change by contraction and positive for a change by expansion) is $-pdV$.

Thus a change in internal energy $dE = dq - pdV$ in consistent units (this avoids having to carry Joule's equivalent J in our work) is attained.

If heat dq is added at constant volume, then $dE = dq$; whereas if the substance is thermally isolated then 'adiabatic' changes take place and $dE = -pdV$. If we are concerned with a gram molecule of substance and heat dq raises its temperature by dT, then the molar specific heat C_v at constant volume is

$$\left(\frac{dq}{dT}\right)_v \qquad \text{which is} \qquad \left(\frac{dE}{dT}\right)_v$$

Enthalpy

It is often convenient to add heat at constant pressure. Under these conditions an integral change of internal energy $(E_2 - E_1) = \Delta E$ is related to the integral change in volume $(V_2 - V_1) = \Delta V$ for an integral amount of heat q by

$$\Delta E = q - p\Delta V$$

Thus the amount of heat added at constant pressure is given by

$$q = \Delta E + p\Delta V$$

It is convenient to use a symbol H for the combination $(E + pV)$ so that since $H = E + pV$, $(dH)_p = dE + pdV$ and $(\Delta H)_p = \Delta E + p\Delta V$. Note, however, that, unless the pressure is constant, $dH = dE - pdV + Vdp$. H is called the enthalpy or, somewhat misleadingly, the heat content and is a term used considerably in chemical and in engineering calculations.

Since the molar specific heat is that amount of heat which causes 1 mol. of substance to change its temperature by 1°

$$C_p = \left(\frac{dH}{dT}\right)_p = \left(\frac{dE}{dT}\right)_p + p\left(\frac{dV}{dT}\right)_p$$

It was seen for the stationary monatomic gas that the energy motion of its molecules could be accounted for at ordinary temperatures as their kinetic energy (the lighter of these substances have very low normal boiling points and thus very small intermolecular potential energy content) and this energy per gram molecule (atom) was

$$\frac{3}{2}RT$$

Thus for the ideal gas it is assumed that internal energy E depends upon temperature only and is independent of volume or

$$\left(\frac{dE}{dV}\right)_T = 0$$

that is, there is no change of internal energy with change of volume at constant temperature.

By using the relationship

$$dE = \left(\frac{dE}{dV}\right)_T \cdot dV + \left(\frac{dE}{dT}\right)_V \cdot dT$$

which says that the resultant change in E is made up of changes first at constant temperature then at constant volume, then, restricted to a condition of constant pressure,

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$$\left(\frac{dE}{dT}\right)_p = \left(\frac{dE}{dV}\right)_T \left(\frac{dV}{dT}\right)_p + \left(\frac{dE}{dT}\right)_v$$

is obtained.

The differential expressions for C_p and C_V previously given then lead to

$$C_p - C_v = \left[p + \left(\frac{dE}{dV}\right)_T \right] \left(\frac{dV}{dT}\right)_p$$

for a substance not undergoing phase change.

For the perfect gas is

$$C_p - C_v = p\left(\frac{dV}{dT}\right)_p = p.\frac{d}{dT}\left(\frac{RT}{p}\right) = R$$

From the association of $\left(\frac{dE}{dV}\right)_T$ with p as the coefficient of $\left(\frac{dV}{dT}\right)_p$ it can be seen that $\left(\frac{dE}{dV}\right)_T$ must have the nature of a pressure. The effective surface pressure p registered by a gauge, and against which mechanical work is done, is in effect the resultant of the thermal pressure as calculated from the kinetic theory, viz. $\frac{RT}{V}$ where V is the molar volume, and the internal cohesive pressure arising from inter-molecular attractions.

Thermal pressure

Thus

$$\left(p + \frac{dE}{dT} \right)_T$$

is the thermal pressure which, in the case of liquids, is very high compared with gases at the same temperature and external pressure. This is because of the larger number of molecules per unit volume in the liquid which, moving with the same molecular speed as these molecules of the same substance in the vapour coexisting with the liquid, transport a tremendously larger amount of momentum per unit time to and from the boundary. This feature also goes some way towards explaining the large difference between liquid and gas viscosities of the same substance, although it does not explain the difference in the temperature dependence of the viscosity in the two cases.

In the calculation of $\frac{\Delta E}{\Delta V}$ accompanying the process of vaporisation, the resultant value of $\left(\frac{dE}{dV}\right)_T$ cannot be used either in the calculation of $(C_p - C_V)$ for a liquid, or for a gas, since the term specific heat has no definite meaning at temperatures and pressures corresponding to two phases coexistent in equilibrium.

Each phase separately will have its own characteristic

$$\left(\frac{dE}{dV}\right)_T$$

In the case of a gram mol. of vapour obeying van der Waal's law

$$\left(p + \frac{a}{V^2} \right) = \left(\frac{RT}{V - b} \right) = \text{corrected thermal pressure.}$$

Obviously

$$\left(\frac{dE}{dV_g}\right)_T = \frac{a}{V^2_g}$$

where V is the molal volume of the liquid region, then by substituting the molal volume of the liquid v for the molal volume of the gas V_g we should have

$$\left(\frac{dE}{dv}\right)_T = \frac{a}{v^2}$$

For liquids

$$\left(\frac{dE}{dv}\right)_T$$

may also be estimated as the latent heat of evaporation (L)/g.mol., less RT, and divided by the volume of 1 g.mol. of liquid, i.e.

$$\left(\frac{dE}{dv}\right)_T = \frac{L - RT}{v}$$

This property has some bearing on the behaviour of mixtures of many organic liquids and is sometimes called the cohesive energy density, as well as the internal pressure.

Conversion of heat into work

When a fixed weight of gas is used as a means of converting heat into work, the gas must go through a succession of cycles of behaviour, each cycle yielding a certain amount of mechanical work. Supposing that such a cycle could be carried out in a cylinder of zero heat capacity, utilising a source of heat at temperature T_1 and a receiver of heat at temperature T_2, and that the gas was imagined to be able to take up heat by conduction at a temperature infinitesimally lower than T_1 and to be able to lose heat when it was infinitesimally higher in temperature than T_2. If a frictionless piston of zero heat capacity is used, then any heat which disappears as such during the cycle should appear at the piston rod as mechanical work.

Maintaining the gas at temperature T_1 while adding heat must involve an isothermal expansion. Since the temperature of the gas has not changed, ideally, the internal energy has not changed

$$dE_{gas} = 0 = dq - pdV$$

Thus

$$q_1 = \frac{RT_1 \cdot dV}{V} = RT_1 \log_e \frac{V_2}{V_1}$$

To get from T_1 to T_2 without taking in or giving out heat (thus avoiding direct heat flow from a source at one temperature to a sink of decidedly different temperature) involves expanding the gas with $dq = 0$. Thus $dE = -pdV$. But for adiabatic expansion the ideal gas follows the law that $pV^\gamma = k$, where $\gamma = C_p/C_V$. For an ideal gas the change of internal energy is

$$-\int_{V_2}^{V_3} \frac{k}{V^\gamma} dV = - \frac{k}{1 - \gamma} (V_3^{1-\gamma} - V_2^{1-\gamma})$$

equivalent to $C_V(T_2 - T_1)$ in loss of energy for an ideal gas.

The giving up of heat 'reversibly' is accomplished during isothermal compression at temperature T_2 until a volume V_4 has been reached such that a further adiabatic compression raises the temperature to T_1 and the pressure to p_1. This must involve the heat change

$$q_2 = RT_2\log_e \frac{V_4}{V_3} = RT_2 \log_e \frac{p_3}{p_4} .$$

which, since $p_3 < p_4$ is of negative sign (i.e. the gas has given it up) together with the final change in internal energy

$$C_V(T_1 - T_2) = \frac{k}{(1 - \gamma)} (V_1^{1-\gamma} - V_4^{1-\gamma})$$

In order to show that $-k(V_1^{1-\gamma} - V_4^{1-\gamma}) -k(V_3^{1-\gamma} - V_2^{1-\gamma}) = 0$ note that $(kV_n^{1-\gamma} = p_nV_n)$.

Thus $p_1V_1 - p_4V_4 + p_3V_3 - p_2V_2 = 0$ has to be shown by $p_2V_2 = p_1V_1$ at T_1 and $p_3V_3 = p_4V_4$ at T_2. A simpler way is to note $C_V(T_2 - T_1) + C_V(T_1 - T_2) = 0$.
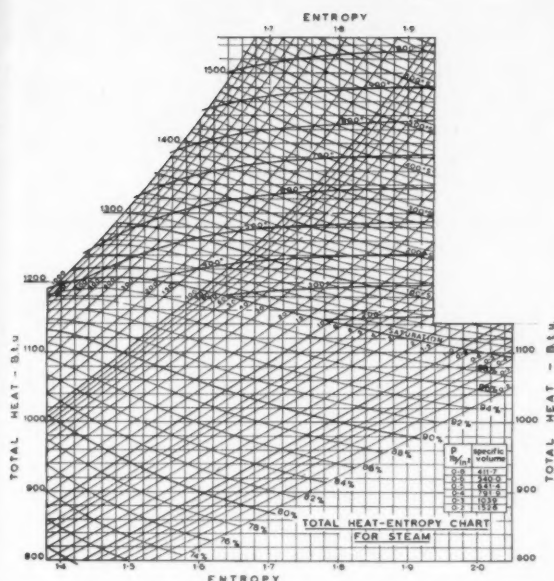
Fig. I. Total Heat-Entropy chart for steam in °F. Plotted by Prof. H. Wright Baker, 1956. Published by Edward Arnold (Publishers) Ltd.

$$\frac{\text{Net heat added to gas in cycle}}{\text{Heat added at } T_1} = \frac{q_1 + q_2}{q_1} =$$

$$\frac{RT_1 \log_e V_2/V_1 + RT_2 \log_e V_4/V_3}{RT_1 \log_e V_2/V_1}$$

or $\dfrac{\text{Heat equivalent of work done}}{\text{Heat added at } T_1}$

Since $p_2 V_2^\gamma = p_3 V_3^\gamma = k$ and $p_1 V_1^\gamma = p_4 V_4^\gamma = k$ so

$$\frac{p_2 V_2^\gamma}{p_1 V_1^\gamma} = \frac{p_3 V_3^\gamma}{p_1 V_4^\gamma}, \quad \frac{RT_1 V_2^{\gamma-1}}{RT_1 V_1^{\gamma-1}} = \frac{RT_2 V_3^{\gamma-1}}{RT V_4^{\gamma-1}}$$

and $\dfrac{V_2}{V_1} = \dfrac{V_3}{V_4}$, the ratio $\dfrac{q_1 + q_2}{q_1} = \dfrac{T_1 - T_2}{T_1}$

By convention q has referred to heat added to the gas—the sign of the expression for q determines whether a positive or negative amount is added. By taking the convention that the direction of heat flowing into the gas is positive (i.e. $q_1^\star$) and the direction of heat flowing out ($q_2^\star$) is negative, while the numerical value $q^\star$ of the heat is always positive, gives

$$\frac{q_1 - q_2}{q_1^\star} = \frac{RT_1 \log_e V_2/V_1 - RT_2 \log_e V_3/V_4}{k T_1 \log_e V_2/V_1} = \frac{T_1 - T_2}{T_1}$$

or $\qquad \dfrac{q_1}{T_1} = \dfrac{q_2}{T_2}$

Entropy

The heat added divided by the absolute temperature at which it is added is called the entropy change ΔS accompanying the heat flow. Thus in the reversible cycle described, the gross entropy change is zero. Had the amount of heat $q_1^\star$ withdrawn at temperature T_1 from the hot reservoir been allowed to flow directly into the cold reservoir at T_2 without the performance of any work then

the entropy change accompanying this flow would be

$$q_1^\star \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$$

i.e. the entropy change of the cold system less the entropy change of the hot system. The result is obviously positive for all $T_2 < T_1$.

The far-reaching result is that, over the reversible cycle, in which the ideal working substance (gas) is returned to its initial condition, the ratio of the heat absorbed (or rejected) to the absolute temperature at which it is absorbed (or rejected) is a constant for the system.

The above demonstration has apparently depended upon the laws governing the behaviour of perfect gases during isothermal compression and adiabatic expansion. However, other substances, say a mixture of pure vapour and pure liquid of the same compound, may be subject to reversible cycles, in which no convenient analytical expressions can be used for determining the effect of each of the four operations in the cycle, but these cycles nevertheless obey the law

$$\frac{q_1}{T_1} = \frac{q_2}{T_2}$$

when empirical data concerning the internal energy as a function of temperature and pressure are applied to each stage of the cycle. In engineering work, because of the predominance of stages of operation involving constant pressure, the function $H = E + pV$ is employed, rather than E, and on the Callendar steam chart the enthalpy H (linear scale) is plotted as a function of the pressure (log scale) of the substance. On this chart are drawn lines of constant temperature, of constant volume, and adiabatic lines, as well as the saturation line.

Once the second law of thermodynamics has been established in the form given, then a reversible adiabatic change can be described as one of constant entropy.

For operations which involve changes of a reversible adiabatic type (cf. flow of gases through nozzles) it is also found convenient to represent the state of a unit quantity of substance graphically by its enthalpy H and its entropy S, each referred to the same arbitrary datum state. Such representations are known as Mollier diagrams. With H and S as co-ordinates, these bear lines of constant temperature, pressure and quality (see Fig. 1).

Estimation of entropy changes

Values of entropy changes are estimated in various ways according to the nature of the change being brought about, but for a fixed amount of a single substance the change of entropy has a unique value once the change in two properties such as the internal energy content and the volume are defined, whilst keeping other things such as pressure and temperature constant. This may be expressed by an equation restating the first law of thermodyanamics in conjunction with the second law, namely $dE = TdS - pdV$ for reversible changes.

Thus, using the definitions of specific heats

$$C_v = \left(\frac{dq}{dT} \right)_V \quad \text{and} \quad C_p = \left(\frac{dq}{dT} \right)_p$$

$$(dS)_p = \frac{C_p dT}{T} \quad (dS)_v = \frac{C_v dT}{T} \quad \text{and} \quad \Delta S_p = C_p \log_e \frac{T_2}{T_1}$$

Generally any change involving alteration of the pressure, volume and temperature can be resolved into a change of temperature at constant pressure, thus reaching a given volume; followed by a change in volume (and pressure) at constant temperature until the desired condition has been reached.

We have already seen that

$$(\Delta S)_p = C_p \log_e \frac{T_2}{T_1}$$

Comparing

$$dS = \frac{dE}{T} + \frac{PdV}{T}$$

with the general expression for a total small change in entropy depending on the independent quantities E and V

$$dS = \left(\frac{dS}{dE}\right)_v . dE + \left(\frac{dS}{dV}\right)_E . dV$$

it is seen that

$$\left(\frac{dS}{dE}\right)_v = \frac{1}{T} \text{ and } \left(\frac{dS}{dV}\right)_E = \frac{p}{T}$$

For a perfect gas, constant E implies constant T, so that the change of entropy brought about by a reversible change in volume at constant T_2 is

$$\Delta S = \int \frac{p}{T_2} . dV \text{ or } \Delta S = R \int_{V_a}^{V_b} \frac{dV}{V} = R \log_e \frac{V_b}{V_a}$$

$$\text{or } -R \log_e \frac{p_b}{p_a}$$

Thus, in taking a mole of perfect gas by reversible processes from $p_1 V_1 T_1$ to $p_2 V_2 T_2$

$$\Delta S = C_p \log_e \frac{T_2}{T_1} - R \log_e \frac{p_2}{p_1}$$

In reality the actual entropy change will be larger than this because of frictional heat, etc. Imperfections in the gas may be allowed for by using empirical relationships such as $pV = CRT$, where C is called a compressibility factor which will not vary much over a limited range of temperatures and pressures. Values of C for different gases at various p and T are tabulated in handbooks of physical and chemical data.

An increase in entropy takes place when two gases, original at the same temperature and pressure, are mixed with one another. Although the mixing is not a reversible process, the unmixing or separation can be imagined to be achievable by a reversible process by utilising special semi-permeable membrane. If one g.mol. of each of the pure ideal gases (A and B) were initially at the same pressure $p_A = p_B$, then mixing them at the same total pressure and temperature involves halving the partial pressure of each gas. The entropy change, in restoring them reversibly to the original pure state would be

$$-R \log_e \frac{p_A}{(p_A)/_2}$$

for each, i.e. $-R \log_e 2$ for each. Thus the entropy increase on mixing will be of this magnitude, viz. ($R \log_e 2$) $\times$ 2, and positive in sign.

Processing of Nuclear Fuels

introduced on a commercial scale, the throughputs of fuel will be much greater and will necessitate the development of geometrically limited equipment with much greater capacities than the designs at present available. Finally, in any plant handling high throughputs of fissile material, consideration must be given to the detection of a criticality incident and the action to be taken in such an eventuality, since it is impossible to give an absolute guarantee that no unforeseen circumstances can lead to an accident. The provision of radiation monitors is important as it is conceivable for there to be no other indication of an incident.

Conclusions

The design of chemical plants to handle high throughputs of fissile material is complicated by the necessity of preventing the formation of a critical assembly. Mass limitation is in most cases impracticable. Where the volumetric throughputs involved are too high for the use of the present types of geometrically limited equipment, and where it is impracticable to monitor the concentration of fissile material continuously at all points, the sensitive point concept has been

evolved whereby the most sensitive points for accumulation of fissile material during mal-operation are determined and protected by suitable instrumentation.

It is clear, however, that in the future even more difficult criticality problems will be presented by the need to process large quantities of higher enrichment material than at present contemplated. Such problems will certainly accompany the introduction of commercial fast reactors. In such cases the use of concentration limitation may be impossible and, therefore, in order to avoid the use of large numbers of parallel lines of the type of ever-safe equipment at present available, it is essential that effort should be given to the development of geometrically limited plant capable of taking high volumetric throughputs. In this context it is important that geometrically ever-safe equipment should be available for each stage of the process, since the strength of a chain is determined by the strength of its weakest link. Thus ever-safe dissolvers, evaporators, extractors, storage tanks, etc., will all be necessary. The lack of such equipment could have a material effect on the cost of power produced by more advanced types of reactors.

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Butyl rubber plant

Esso Petroleum Co. Ltd. are to construct a plant at their refinery in Fawley for the manufacture of butyl rubber. The new plant, which will cost about £4.3 million and which will have a capacity of 30,000 tons p.a., will take between two and three years to build.

Butyl rubber is mainly employed in the manufacture of inner tubes. It has also established itself for use in electric cables, conveyor belts, tank linings and rubber components as a general-purpose rubber exhibiting superior resistance to heat, chemical attack and atmospheric weathering.

The capacity of the new plant, when completed, is expected to meet all U.K. requirements for butyl rubber for a considerable period and will permit the company to supply export markets.

Materials of Construction for Chemical Plant

POLYOLEFINES

By L. A. Muirhead,* B.Sc., A.R.I.C.
and T. S. McRoberts,* B.Sc., M.Sc., Ph.D.

This is the sixth article in our series on Materials of Construction for Chemical Plant—previous articles in this series have included PVC, lead, nickel, stainless steel and graphite. The class of polyolefines includes both polyethylene and polypropylene which, as far as the chemical plant designer is concerned, are fairly similar. Ethylene was already polymerised by a high-pressure process in 1933, but only during the past decade have the newer methods of polymerising ethylene and propylene, discovered by Ziegler and Natta, been successfully developed. This article surveys the properties of low-density polyethylene, high-density polyethylene and polypropylene and describes their usefulness to the present-day chemical plant constructor.
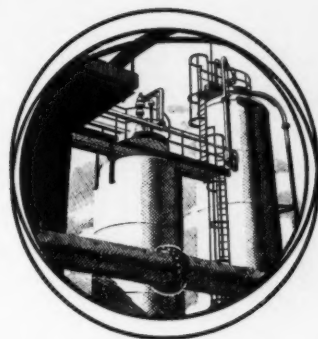
THERE are many applications for plastics in the chemical industry, and of these, one of the most important is for the manufacture of pipes and linings for pipes and vessels. Other typical applications include the manufacture of laboratory and industrial plant and equipment, the fabrication of protective clothing and various forms of heat insulation.

The main types of plastic which have established themselves in the chemical industry are the polyolefines, PVC, polyamides, glass - reinforced epoxy- and polyester resins, phenolics and polytetrafluoroethylene. These materials have become established for the following main reasons:

(a) High resistance to corrosion.
(b) Ease of fabrication.
(c) Low maintenance costs.
(d) Light weight.

In common with all other materials, however, plastics have certain limitations, and therefore each application (especially where contact with mixtures of chemicals is involved) should be considered individually, and pilot-scale tests should be carried out where it is considered desirable. For instance, the temperature limitations of the plastic concerned must be taken into account, particularly if the material is to be subjected to a continuous stress. Where this may be the case, the difficulty can often be overcome by using the plastic in conjunction with metal, either as a lining or a sleeve. By this means, the high chemical resistance of the plastic is combined with the high mechanical strength of the metal.

Among the various types of plastic currently in use, it is clear that the polyolefines form one of the most rapidly expanding groups.

Process for manufacture

The first practical step in the development of polyolefines as plastics occurred when gaseous ethylene was polymerised at high pressure on a laboratory scale in 1933, to give a low-density polyethylene. Since then, as a result of steady development work, polyethylene has become one of the most important plastic materials and is used extensively in many different types of industry. Up to about 1950 the only method of preparing polyethylene was still the high-pressure process involving the polymerisation of ethylene gas at or about 1,000 atmospheres and yielding a relatively flexible polymer. In 1950, however, new methods of preparing polyethylene were discovered principally by Ziegler in Germany and the Phillips Petroleum Co. in the U.S.A., in which the use of high pressures was unnecessary.

The Ziegler and Phillips processes for polyethylene manufacture can be operated at atmospheric, or comparatively low pressure with corresponding saving in the power consumption required for the high-pressure process. On the other hand, a hydrocarbon reaction medium is necessary for the low-pressure processes, this hydrocarbon being recovered from the product and re-cycled to the process. It is essential also to remove catalyst remnants from the product to obtain satisfactory product performance. The efficiency of hydrocarbon recovery and

catalyst removal play an important part in the economics of the low-pressure processes.

Further development of the Ziegler catalyst system by Natta resulted in a process for manufacture of isotactic polypropylene and other stereo specific polymers, thus enhancing the flexibility of the Ziegler process; the extent of this flexibility is being explored today by almost every university and large chemical company in the world.

Molecular arrangement

Irrespective of whether the polymer is produced by the high-pressure or low-pressure method, the polyethylene molecule consists basically of poly-methylene units with side chains positioned along the chain. In the case of the low-pressure route, these side chains are greatly reduced in number, thus enabling the molecules to fit easily into a more regular lattice, thereby giving a high degree of crystallinity.

In polyethylenes prepared by the high-pressure method, the individual molecular chains are considerably more branched, and consequently the resultant polymers have an appreciably lower crystallinity than the low-pressure products. This means that these polymers are softer, more flexible and have lower tensile strength characteristics than their more linear counterparts, arising from the low-pressure processes.

As far as the commercial polypropylenes are concerned, the polymers contain several molecular forms, including the isotactic and the atactic. The regular isotactic form which is diagrammatically represented in Fig. 1, is the predominating configuration in normal commercial grades and is responsible for the excellent properties which are characteristic of these polymers. Atactic polypropylene is a rubbery material of low strength and has as yet little commercial interest.
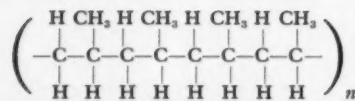
$$\left(\begin{array}{c} \text{H CH}_3 \text{ H CH}_3 \text{ H CH}_3 \text{ H CH}_3 \\ -\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}- \\ \text{H H H H H H H H} \end{array} \right)_n$$

Fig. I. Isotactic polypropylene.

The good physical properties of isotactic polypropylene can be attributed to the ordered arrangement of the side groups ($-CH_3$) which permits the main chains to lie close to one another. This proximity enables substantial areas of crystallinity to occur within the polymer, with the result that certain physical characteristics such as tensile strength are enhanced.

It will be seen, therefore, that with

Table I. Comparative properties of polypropylene, low- and high-density polyethylenes

Material property	Polypropylene	High-density polyethylene	Low-density polyethylene
Density, g./c.c.	0.90 to 0.91	0.935 to 0.965	0.91 to 0.93
Modulus of elasticity, p.s.i. $\times 10^5$	1.4 to 2.1	0.5 to 1.5	0.19 to 0.35
Tensile strength, p.s.i.	3,500 to 5,500	2,800 to 5,000	1,500 to 2,000
Impact strength (20° to 25°C.), ft.lb./in. notch	1 to 5	1 to 6	16
Softening point (°C.) (Vicat)	150	120 to 128	80 to 90
Mould shrinkage, in./in...	0.01 to 0.025	0.01 to 0.04	0.02 to 0.05

the commercial availability of these various types of polyolefines, designers of chemical plant have access to a class of materials having a wide spectrum of physical properties ranging from somewhat soft, resilient products to materials having rigid and heat-resisting characteristics. The typical physical properties of these three types of materials are shown in Table 1.

Performance

Unlike some other plastics such as PVC, polyolefines do not normally require modification by the addition of plasticisers, stabilisers, etc., and normally the choice of the desired physical properties is made by selecting the correct grade of polyolefine, both with respect to density and molecular weight. Sometimes, however, compounding is carried out with various additives such as anti-oxidants, to improve heat stability characteristics, or carbon black, to improve the resistance to ultra-violet light.

Because of the importance of the individual behaviour characteristics under operating conditions, certain general remarks are made below which it is hoped will be of value to the chemical plant designer.

Resistance to elevated temperatures

For short-term work, *i.e.* intermittent operation, low-density polyethylene, high-density polyethylene and polypropylene may be used in installations when operating temperatures up to 75°C., 100°C. and 125°C. respectively are encountered. This assumes that the plastic in question is subject to negligible stress, as otherwise at these temperatures deformation is liable to occur.

For long-term service at elevated temperatures (because of the short time in which high-density polyethylene and polypropylene have been available) it is difficult to give an all-embracing statement. However, generally speaking, providing that temperatures of 65°C. are not exceeded, all the three types of plastics considered should be suitable under low stress conditions. The ability of high-density polyethylene and polypropylene to be maintained at higher temperatures than this is dependent to a large extent on the stabilising system employed. If the plastic is subjected to stress at elevated temperatures, creep becomes important.
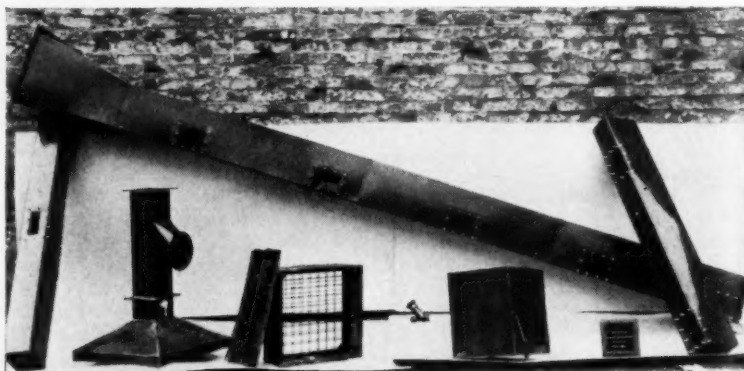
Considerable work is in hand so

Fig. 2. Ducting hoods, tanks, ventilation grilles and filter casings for use in chemical plant work made from Shell Chemical Co.'s ' Carlona.' polypropylene by ManMil Plastics Ltd.

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that the actual operating life of these polymers at temperatures up to and above 100°C. can be established. From this work it is hoped that plastic hot-water pipes will become a commercial feasibility.

Structural applications

Until a short while ago, low-density polyethylene was the only type of polyolefine available for chemical plant. The relatively low rigidity of this material, however, precluded its use in applications where it was subjected to heavy loading. Although both high-density polyethylene and polypropylene are considerably more rigid, it is unlikely that they will become accepted for load-bearing purposes, because they are still relatively soft materials when compared with plastics already used in this field, such as phenolics, rigid PVC, and glass-reinforced polyesters. Where for certain reasons, however, polyolefines are required to sustain appreciable loadings, it is important to remember that the creep in high-density polyethylene and polypropylene is considerably lower than that for low-density polyethylene.

Toughness characteristics

For chemical plant work, a high impact resistance is an important characteristic. Both low- and high-density polyethylene are outstanding in this respect, even for temperatures as low as –30° and –70°C. respectively. Polypropylene, too, has excellent impact strength at normal temperatures,

Fig. 3. A fan unit and absorption unit made by Resistant Equipment Ltd. from high-density polyethylene.

Fig. 4. Superseding wooden slats in water-cooling towers, these grids made from 'Carlona' high-density polyethylene measure about 3 ft. sq. and weigh 4 lb. They are moulded by Ekco Plastics Ltd. for Head Wrightson Processes Ltd. For applications in which the water contains no hydrocarbons, high-impact polystyrene may be used in place of polyethylene and the mould was designed to use either material.

but at about 0°C., loss in impact strength is noted. Where maximum abrasion resistance is required, as well as high impact, the higher molecular weight grades of high-density polyethylene are particularly suited.

Chemical resistance

Polyolefines are among the most resistant plastic materials and they can be recommended for handling weak and strong acids and alkalis and most other types of aqueous solutions as long as strong oxidising conditions are absent. In contact with organic chemicals, particularly some of the more active solvents, the application of polyolefines needs some considerable care if success is to be ensured. Although high-density polyethylene can be used indefinitely with paraffinic hydrocarbons of both the kerosene and lubricating oil type, the low-density polymers cannot normally be recommended for use with kerosene.

In applications of low- and high-density polyethylene for chemical-resistant work, it is a general rule to use as high a molecular weight polymer as fabrication techniques permit to obtain maximum chemical resistance.

As far as polypropylene is concerned, there has been insufficient time to

carry out long-term chemical resistance tests, but due to its high resistance to stress cracking, this polymer should become of considerable interest in this field. Table 2 gives typical chemical resistance characteristics of high-density and low-density polyethylenes.

Table 2. Typical chemical resistance of high- and low-density polyethylene

	High-density	Low-density
Sulphuric acid (up to 50%)	S	S
Kerosene	S	
Lubricating oil ..	S	S
Benzene	U	U
Anionic detergents..	S	S
Fruit juices (30%)..	S	S
Sodium hydroxide..	S	S

S = Satisfactory
U = Not recommended

Outdoor exposure

All grades of polyolefines are suitable for outdoor exposure, providing they are pigmented with about 2% of carbon black. Although there is a number of U.V. screening agents commercially available, the use of some colours, including pastel shades, cannot yet be fully recommended for
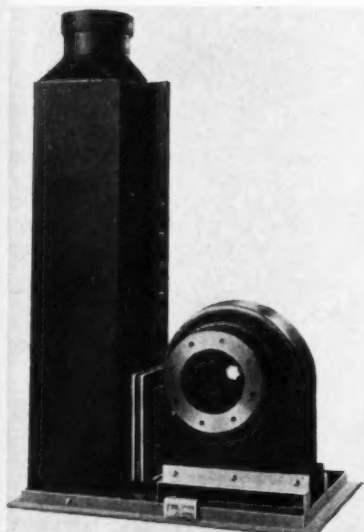
indefinite outdoor exposure, owing to the lack of adequate field trials for this type of formulation.

Application and fabrication

Polyolefines can be fabricated for chemical plant usage by the usual methods, *viz.* injection and compression moulding, extrusion, blow extrusion, welding, machining from block and by other specialised methods, including coating from the powdered polymer either by flame-spraying, or by dipping.

Typical examples of injection moulding include items of chemical equipment such as beakers, measuring cylinders, buckets, funnels, etc., and these have been produced in low-density polyethylene for many years. High-density polyethylene and polypropylene, because of their greater rigidity and better chemical resistance, are now beginning to find applications in this type of usage.

Extruded polyethylene pipe, both of the low-density and high-density variety, has been available to the chemical industry for a number of years. It has become widely accepted in chemical plants, as well as in research laboratories and for water service applications because of its resistance to chemical attack and its general longevity characteristics. This application is widened by the range of pipe fittings now available moulded in the appropriate plastic. These fittings are joined to the plastic pipe, usually by a heat fusion process, and a number of methods allow jointing to be carried out conveniently on site. A point which is of considerable importance to the chemical engineer is that pipes and screw-in fittings conforming to the standard steel pipe sizes (*i.e.* B.S. 1387) are now available, and this means that corroded metal pipe can be replaced section by section by plastic pipe. Tank liners, ventilation ducts and wide-bore piping can be fabricated from the three main types of polyolefines by suitable welding techniques. The method using a welding rod with a hot-air torch has

Fig. 5. Exhaust system for plating tanks made by Resistant Equipment Ltd. from high-density polyethylene.
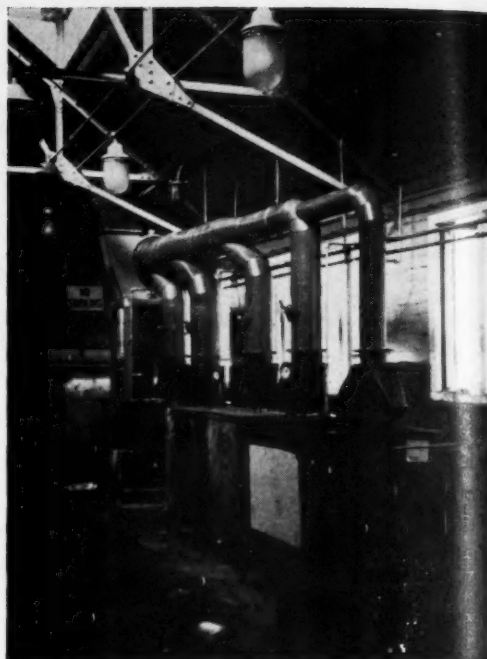
become firmly established with the low-density materials, whilst the use of the butt-welding technique seems to be the preferred process for high-density polyethylene. A number of companies are commercially producing an apparatus which, using this technique, can join polyolefine sheeting on a works scale and certain models are able to produce complex butt-welded shapes.

Powdered plastics

In recent years, considerable development has occurred in the application of powdered plastics to produce protective coatings and liners for chemical plant. Basically, in this process, powdered polymer is brought into contact with a heated surface, thereby causing fusion of the polymer particles to occur. In due course, the molten particles coalesce, and a continuous coating is formed.

Coatings using this method can be conveniently carried out with polyolefines, particularly low-density polyethylene, using either flame-spraying, sintering or dipping methods. Commercial applications of this process include the production of removable drum liners, the linings for vessels and tanks generally, and the production of self-supporting tanks for the storage of chemicals.

Recent developments have enabled high-density polyethylene to be produced in the form of porous sheet. By variation of manufacturing con-

ditions, the porosity of the product can be altered without difficulty, and such materials find use for either filter applications or a convenient means of aerating corrosive liquids. Other applications in the pneumatic transport of powders are also being considered.

The use of low-density polyethylene for the packaging of chemicals both in small and large containers is increasing rapidly. The introduction of high-density polyethylene enabling rigid containers of comparatively low wall thickness to be made will accelerate this development. Obviously, in the transport of chemicals such as acids, where glass carboys have hitherto been used, there exists a most attractive field for large unbreakable plastic containers.

In the last ten years, continuation of the work started by Ziegler and Natta has resulted in considerable developments in polyolefine chemistry generally. It is evident that isotactic polybutylenes and higher homologues will merit considerable investigation, but it is likely that practical interest will remain concentrated on polymers produced from ethylene and propylene, mainly because of availability or cost of the monomer. Considerable developments, however, are to be expected by either blending techniques or by co-polymerisation methods. Indeed, certain co-polymers of ethylene and butylene have recently been produced on a commercial scale.

Thermal Conduction and its Special Application to Thermal Insulation

By H. K. Suttle,[*] M.I.Chem.E., F.R.I.C., M.Inst.F.   Part 2

Theories of transient heat conduction are considered in the second part of this article on thermal conduction. Appropriate equations are derived and their use in graphical form demonstrates the solution of many conditions during unsteady-state heat transfer. Finally, two appendices containing worked examples illustrate the application of various theoretical equations derived in this article, in determining optimum insulation.

THE situation to be considered is that which would exist if a sudden temperature change were to occur at the surface of a solid previously held at a uniform temperature. Unidirectional conduction in a thick plate is chosen for illustration, in which the heat flow is assumed to proceed from a surface in the x-direction into the interior of a plate. The plate is visualised as being infinitely wide or, what amounts to the same idea, completely insulated at the edges, and a thickness which can be described as 'infinitely' thick. This is the case of the 'semi-infinite solid' discussed fully by Carslaw.[3]

The appropriate equation for the linear heat flow is

$$\frac{\partial^2 t}{\partial x^2} - \frac{1}{\alpha} \cdot \frac{\partial t}{\partial \theta} = 0 \quad \dots \dots \dots \dots \dots \quad (51)$$

A solution of this equation is the expression

$$u = \theta^{-\frac{1}{2}} e^{\frac{-x^2}{4\alpha\theta}} \quad \dots \dots \dots \dots \dots \dots \quad (52)$$

which may be demonstrated by differentiating equation (52) and substituting into equation (51).

The properties of the solution (52) are of some interest, for as θ becomes zero and a point which is not at the surface is not zero then the value of u tends towards zero. If, however, θ tends to zero and x is equal to zero (that is, a point on the surface) then u tends to infinity. The result shown as follows is known as the 'source solution', namely

$$\int_{-\infty}^{\infty} u \, dx = 2\sqrt{\pi\alpha}$$

for all values of θ greater than zero. The physical explanation is that this solution corresponds to the release of the quantity of heat represented by $2\rho c\sqrt{\pi\alpha}$ over unit area of the plane at $x = 0$ and $\theta = 0$.

Equation (51) is also satisfied by the following

$$\int_0^x \theta^{-\frac{1}{2}} e^{\frac{-x^2}{4\alpha\theta}} \, dx = 2\alpha^{\frac{1}{2}} \int_0^{\frac{x}{2\sqrt{\alpha\theta}}} e^{-z^2} \, d\xi$$

This expression enables the introduction of Gauss's error function, and the solution is the 'error function solution'. The notation of the error function is

$$\mathrm{erf}\, x = \frac{2}{\sqrt{\pi}} \int_0^x e^{-z^2} \, d\xi \quad \dots \dots \dots \dots \quad (53)$$

and a little consideration will show that a solution of equation (51) is also

$$M \,\mathrm{erf}\, \frac{x}{2\sqrt{\alpha\theta}} \quad \dots \dots \dots \dots \dots \dots \dots \quad (54)$$

where M is an arbitrary constant.

Let the initial temperature of the slab be t_i throughout. At a time $\theta = 0$ the surface temperature is suddenly changed to a zero value and thereafter remains at this temperature. The properties of the error function satisfy these boundary conditions, in addition to the differential equation. For these reasons, there may be written

$$t = t_i \,\mathrm{erf}\, \frac{x}{2\sqrt{\alpha\theta}} \quad \dots \dots \dots \dots \dots \quad (55)$$

The parameter

$$\left(\frac{x}{2\sqrt{\alpha\theta}} \right)$$

is a dimensionless quantity from which important deductions can be made.

The last equation may be written

$$\frac{t}{t_i} = f \frac{x}{2\sqrt{\alpha\theta}} = \mathrm{erf}\, \frac{x}{2\sqrt{\alpha\theta}}$$

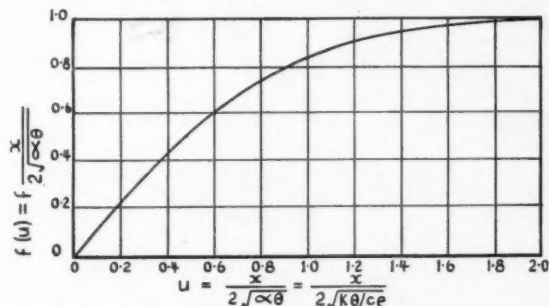which gives a form suitable for plotting. This is shown

Fig. 8. Temperature variation in an infinitely thick slab when the surface temperature is suddenly changed. For values of u less than 0.75, $f(u)$ is approximately equal to u. For values of u larger than 1.5, $f(u)$ is approximately equal to unity.

in Fig. 8 where the values of the error integral

$$f\left(\frac{x}{2\sqrt{\alpha\theta}} \right)$$

Senior Lecturer, Department of Chemical Engineering, College of Technology, Loughborough.

are plotted as ordinates against

$$\left(\frac{x}{2\sqrt{\alpha\theta}}\right)$$

as abscissa. The use of this chart may be illustrated where it is required to know the time to reach a temperature such that

$$\left(\frac{t}{t_i}\right)$$

has the value 0.25 at a depth of 10 cm. (4 in.) in a dry, plane, concrete structure for which the diffusivity is $\alpha = 0.0042$ sq.cm./sec. From the ordinate 0.25 read

$$\left(\frac{x}{2\sqrt{\alpha\theta}}\right) = 0.22$$

The value of the time (θ) is $12.4(10^4)$ sec., or 34.4 hr. The same calculation for mild steel $(\alpha = 0.12)$ gives a result of 1.2 hr.

It is convenient to write equation (55) as $t = t_i f(u)$, and to adjust the temperature scale so that the relation applies for a surface temperature t_s which is not zero. The resulting expression is $(t - t_s) = (t_i - t_s) f(u)$, or

$$\frac{t - t_s}{t_i - t_s} = f(u) \quad\quad\quad\quad (56)$$

The physical significance of this is shown by the cooling curve in Fig. 9. It will be readily seen that this fraction represents the degree of completion of the process at any time θ. Similarly, for heating of the body, the ordinate represents the quantity

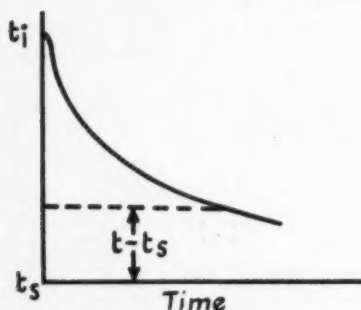$$\left(\frac{t_s - t}{t_s - t_i}\right)$$

Fig. 9.

Although the discussion hitherto has been concerned with 'semi-infinite solid', the expression (56) can be applied with little error to a body of finite thickness until such a time has elapsed that the temperature of the opposite surface has altered appreciably. It will be apparent that when such a point is reached there will be a further heat-transfer process from the second surface into the environment. Further study of equation (55) will show that the time required for a particular point to attain to a given temperature varies inversely as the *diffusivity*. In addition, it is easily seen that a temperature (t) is attained at the distances x_1 and x_2 from the surface in times θ_1 and θ_2, such that

$$\frac{x_1}{2\sqrt{\alpha\theta_1}} = \frac{x_2}{2\sqrt{\alpha\theta_2}}$$

from which

$$\frac{\theta_1}{\theta_2} = \frac{x_1{}^2}{x_2{}^2} \quad\quad\quad\quad (57)$$

This result is sometimes known as the 'law of times' and states that 'the times required for any two points to reach the same temperature are proportional to the squares of the distances from the boundary planes'. This applies, of course, to both heating and cooling and the only condition is that the surface temperature remains constant.

The rate at which heat flows into or out of a body which is initially at t_i and with the surface temperature changed to t_s, through an area A of plane surface in the x-direction, is given by

$$q = kA \frac{(t_i - t_s) e^{-x^2/4\alpha\theta}}{\sqrt{\pi\alpha\theta}} \quad\quad\quad\quad (58)$$

If interest centres on the heat entering the plate, that is for the boundary, $x = 0$, the above expression is written

$$q_s = \frac{kA(t_i - t_s)}{\sqrt{\pi\alpha\theta}} \quad\quad\quad\quad (59)$$

The total heat inflow during the time interval $(\theta = 0)$ to $(\theta = \theta)$ is obtained from the integration of equation (59), namely,

$$Q_s = \int_{\theta\,=\,0}^{\theta\,=\,\theta} q_s.\ d\theta = 2kA(t_i - t_s)\sqrt{\frac{\theta}{\pi\alpha}} \quad\ldots (60)$$

An important industrial problem is the temperature which would result in a solid, the boundaries of which are two parallel planes, when these two opposite surfaces are simultaneously brought to a steady temperature, different to the initial temperature (t_i) of the solid, after a time (θ). Generally, interest attaches to the probable temperature at the middle point of such a slab, although the temperature distribution at various times may be significant in certain applications as, for example, furnace structures and in the investigation of the properties of refractories. Mathematical solutions for a number of the geometrically simple shapes[3, 5, 7] have been obtained, and the results presented in convenient form as charts.

The problem considered here is the temperature (t_c) which would be attained, under the above conditions, at the centre of a plane slab having a total linear dimension in the x-direction of $2l$. The centre point is, therefore, at the distance l from one surface. The surfaces are brought to a temperature (t_s) and it is required to find the value of t_c after an elapse of time θ.

The basis of such presentations is a plot of the appropriate excess temperatures, in the form of a ratio, against the dimensionless group, $\alpha\theta/l^2$. The temperature ratio is shown[7] to be a function of the series

$$S(z) = \frac{4}{\pi} (e^{-\pi^2 z} - \tfrac{1}{3}e^{-9\pi^2 z} + \tfrac{1}{5}e^{-25\pi^2 z} - \ldots)$$

in which z represents the group $\alpha\theta/l^2$. Values for the series are available, and the appropriate graph is given in Fig. 10.

Where surfaces are exposed to the other influences which affect heat-transfer calculations, namely convection and thermal radiation, then these must be allowed for in order to obtain accurate values of the heat energy transferred. Although it is not intended to discuss these factors, notes are given in the appendix and their use is shown in an example calculation.

The practising engineer will consider these features and, in addition, the economic factors so essential to the choice of a scheme of comprehensive insulation.

Conclusion

The foregoing presentation, of necessity, is concerned with the fundamental conceptions only of what is, indeed, a very large and important subject. It has been shown that
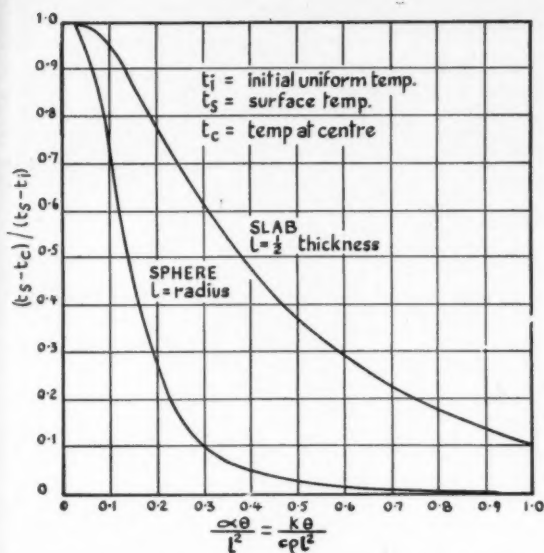
Fig. 10. Temperature change at the centre of a slab and a sphere caused by a sudden change of the surface temperature

several complex mathematical calculations necessary for a full understanding of the topic may be arranged in a form suitable for quite elementary computation. This is particularly the case with transient conduction and the whole problem of unsteady heat conduction, and convenient charts for particular shapes have been prepared.[5, 15] Although these are of great value, problems are encountered in practice where both surface temperature and thermal diffusivity may vary, and for such cases formal mathematical solutions are extremely difficult. These are largely overcome by the use of ' models ' which represent the process under investigation—usually an electrical or a hydraulic analogue. Other approximate methods of computation are contained within the scope of numerical and graphical methods,[10] including relaxation procedures and the adaptation of the calculus of finite differences to a graphical procedure.

Acknowledgments are given to the eminent authors of the books which have so freely been consulted, and without which this article would not easily have been presented.

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APPENDIX I

Thermal conductivity of insulating materials

Material	Density, lb./cu.ft.	Conditions	Conductivity, B.Th.U./(sq.ft.)(hr.)(°F./in.)
Baked slab cork*	7.7	Dry at 21°F. (mean)	0.28
	7.7	Dry at 39°F. (mean)	0.31
	7.7	49% moisture at 21°F. (mean)	0.38
	dry		
	7.7	49% moisture at 39°F. (mean)	0.37
	dry		
Cellular concrete*	19.25	Dry at 75°F. (mean)	0.55
	19.50	7% moisture at 75°F. (mean)	0.59
	23.50	22% moisture at 73°F. (mean)	0.90
Diatomaceous bricks*	30.00	Dry at 63°F. (mean)	0.99
		43% moisture (on net weight) at 63°F. (mean)	3.10
Water*	—	At 50°F. (mean)	4.3
Foamed polystyrene†	1.0	Average values for the temperature	0.151
Foamed PVC†	7.7	range +20 to –183	0.224
Silica aerodel†	4.3	°C.	0.098

*Reference 2
†Adapted from values given in ' Low Temperature Techniques ', by F. Din and A. H. Cockett. G. Newnes Ltd., London.

APPENDIX II

The rate of heat transfer by a convection process between a surface and its environment may be stated by the expression

$$q_c = h_c A_s (t_s - t_e)$$

in which h_c is the appropriate heat-transfer coefficient, A_s is the surface area and t represents the respective temperatures. The quantity h_c may be a function of several properties and conditions, according to whether the fluid in contact with the surface is moving in a streamline or a turbulent fashion. For many cases encountered in heat insulation technique the flow is the slow, streamline motion typical of a current of hot air rising along a heated surface. The motion is termed natural convection and a suitable general expression for h_c is as follows:[15]

$$h_c = 0.30 (t_s - t_e)^{0.25} \text{ B.Th.U./(sq.ft.)(hr.)(°F.)}$$

and t_s, t_e are expressed in °F.

When the fluid motion is much more violent, more complex expressions are necessary.

The rate of heat transfer by radiation from the surface of the heated pipe, or enclosure, to the boundaries of the environment is given by

$$q_r = 0.173 E_s A_s \left[\left(\frac{T_s}{100} \right)^4 - \left(\frac{T_e}{100} \right)^4 \right]$$

in which the respective temperatures (T_s, T_e) are expressed in absolute units (°R), and E_s is the emissivity of the surface.

If this equation is written

$$q_r = h_r A_s (t_s - t_e)$$

it will be observed that the fourth powers of the absolute temperatures are eliminated and the calculation is simplified by the use of the ordinary temperature difference. The value of h_r is obtained from

$$h_r = \frac{q_r}{A_s (t_s - t_e)} = \frac{0.173 E_s [(T_s/100)^4 - (T_e/100)^4]}{(T_s - T_e)}$$

The total rate of heat loss from the surface q_t is
$$q_t = q_c + q_r = (h_c + h_r)A_s(t_s - t_e)$$
The quantity $(h_c + h_r)$ is represented by the term h in the earlier discussion.

Example 1. The plane wall of a furnace is built up as shown in the sketch, and under steady operating conditions the inner surface of the lining attains to 1,650°F. whereas the outer surface of the wall remains at 100°F.

The values of k are given in ft./hr. units. Under these conditions, the heat loss per square foot of surface may be found, and also the temperatures at the interfaces of the layers of the wall.

	Firebrick	Insulating brick	Building brick	
1,650°F.	8 in. $k = 0.62$ t_1 (a)	4 in. $k = 0.09$ t_2 (b)	9 in. $k = 0.40$ (c)	100°F.

Using equations (23) to (25), find the thermal resistances of each section, as follows:

$$R_a = \frac{8/12}{(0.62)\ (A)} = 1.08A$$

$$R_b = \frac{4/12}{(0.09)\ (A)} = 3.70A$$

$$R_c = \frac{9/12}{(0.40)\ (A)} = 1.87A$$
$$\overline{6.65A}$$

As the basis is 1 sq. ft., $A = 1$, and the rate of heat transfer is easily found from

$$q = \frac{1,650 - 100}{6.65} = 233\ \text{B.Th.U.}/(\text{sq.ft.})(\text{hr.})$$

The temperature drop (Δt) across section (a) is $\Delta t = qR$, therefore,

$$\Delta t_a = (233)\ (1.08) = 252°$$
whence, $\quad t_1 = 1,650 - 252 = 1,398°\text{F.}$
Similarly, $\quad \Delta t_b = (233)\ (3.70) = 862°$
hence, $\quad t_2 = 1,398 - 862 = 536°\text{F.}$

Example 2. A flat furnace wall is built up of aluminous fireclay blocks 6 in. thick backed with insulating refractory blocks 3 in. thick, the thermal conductivity of which is 0.15 B.Th.U./(sq.ft.) (hr.)(°F./ft.). At steady-stage operation the furnace lining surface is at 1,709°F. and the ambient air temperature is 80°F. The convection coefficient of heat transfer (h_c) from the outer surface is considered to be 1.04 B.Th.U./(sq.ft.)(hr.)(°F.). If the emissivity of the surface is 0.85 and h_c can also be calculated from, $h_c = 0.27\ (t)^{0.25}$, the following information can be found:
(1) The radiation coefficient of heat transfer;
(2) The heat loss from the wall;
(3) The temperature at the interface of the refractories;
(4) The mean thermal conductivity of the furnace lining.
From Appendix II it will be seen that

$$h_c = 0.27\ (t_s - 80)^{0.25} = 1.04$$
from which the value of t_s is found to be 300°F.
Also,

$$h_r = \frac{0.173\ (0.85)\ [(760/100)^4 - (540/100)^4]}{300 - 80} = 1.66$$
thus

$$h_t = h_c + h_r = 2.7$$

and the heat transmitted, with the conditions at the outer surface typical of natural convection, will be given by

$$q = 2.7\ (300 - 80) = 572\ \text{B.Th.U.}/(\text{sq.ft.})(\text{hr.})$$

From equation (21a)

$$q = 572 = \frac{t - 300}{0.25/0.15}$$

from which the interface temperature

$$t = 1,252°\text{F.}$$

If these results are now placed into the general equation for this case

$$572 = \frac{1,709 - 1,252}{0.5/k}$$

solving of which gives the value of
$$k = 0.625\ \text{B.Th.U.}/(\text{sq.ft.})(\text{hr.})(°\text{F./ft.})$$

Example 3. This simple case is given to illustrate the conception of mean area. A thin metal box, 2 ft. $\times$ 2 ft. $\times$ 2 ft., is insulated with a suitable material 6 in. thick, and is used as a storage for a liquid at $-110°$F. The outer surface of the insulation is at 70°F. It is proposed to construct a spherical container of the same material and of the same cubic capacity, and to insulate it in the same manner as the original box. Thermal conductivity of the insulation is 0.022 ft./hr. units. Calculate the heat leak in each case.
Using equation (46)

$$A_t = 6 \times 2 \times 2 = 24\ \text{sq.ft.}$$
$$0.54\ x\,y = 0.54\ (0.5)\ (8 + 8 + 8) = 6.48$$
$$1.2\ x^2 = 1.2\ (0.5)\ (0.5) = 0.30$$
$$A_m = 30.78\ \text{sq. ft.}$$
$$R = 0.5/(0.022)\ (30.78)$$
$$q = \Delta t/R = 244\ \text{B.Th.U.}/\text{hr.}$$

Volume of box = 8 cu. ft., from which the equivalent radius of the sphere will be 1.24 ft.
A_m for sphere is given by
$$4\pi r_1 r_2 = 27.1$$
Using this value and calculating as before
$$q = 214.5\ \text{B.Th.U.}/\text{hr.}$$

Example 4. Cellular concrete has a thermal conductivity (Appendix I) of $0.55/12 = 0.046$ ft./hr. units. Its density is 19.25 lb./cu.ft. and the specific heat will be close to 0.20. If a slab of this material 4 in. thick is at 60°F. and is placed between two hot plates at 250°F. the temperature at the centre of the slab after a period of 1 hr. may be found by the use of Fig. 10.
The group

$$\frac{k\theta}{c\,l^2} = \frac{(0.046)\ (1)\ (6)\ (6)}{(0.20)\ (19.25)} = 0.47$$

Thus

$$\frac{(250 - t_c)}{(250 - 60)} = 0.40$$

from which the centre temperature is found to be 174°F.

NOMENCLATURE

(Units commonly used are given in parentheses)

A = Area (sq.ft.)
E = Emissivity, in thermal radiation
M, N = Numerical constants
Q = Quantity of heat (B.Th.U.)
R = Thermal resistance
T = Absolute temperature (°R = °F., *i.e.* °F., absolute)
$[L], [M], [T]$ = Dimensions of mass, length and time, respectively
c = Specific heat (B.Th.U./lb. °F.) (c_p, specific heat at constant pressure, may be used)
f = Heat flux
$\mathbf{f}$ = Flux vector
h = Film coefficient of heat transfer {B.Th.U./(sq.ft.)(hr.)(°F.)}
k = Thermal conductivity {B.Th.U./(sq.ft.)(hr.)(°F./ft.)}
l = Typical dimension (ft.)
q = Rate of heat transfer {B.Th.U./(sq.ft.)(hr.)}
r = Radius
t = Temperature (°F.)
u = Function
x = Distance (ft.)
α = Thermal diffusivity (sq.ft./hr.)
β = Constant in thermal conductivity equation
ϕ = Angle (latitude)
ζ = Angle (azimuth)
θ = Time
λ, μ, ν = Direction cosines
ρ = Density
φ = Angle; shape factor; (function)
ψ = Function
Δ = Area; difference

Subscripts:
i = Initial conditions
s = Relating to surface
e = Relating to environment
r = Implying radiation
c = Implying convection
t = A total value

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What's New

in Plant • Equipment • Materials • Processes

CPE reference numbers are appended to all items appearing in these pages to make it easy for readers to obtain quickly, and free of charge, full details of any equipment, machinery, materials, processes, etc., in which they are interested. Simply fill in the top postcard attached, giving the appropriate reference number(s), and post it.

Beryllium survey monitor.

Chlorinators

The range of chlorinators developed by Chlorination Equipment Ltd. has been increased by the addition of a large-capacity-type instrument which provides up to 350 lb./hr. of chlorine. The design incorporates all the salient features of the existing models and in addition includes an adjustable injector assembly.

All the components of this chlorinator are said to be corrosion-proof, those which cannot be made of plastic material being of corrosion-resistant metal.

The chlorinators are said to be easy to install and simple to operate. Only one control has to be manipulated to vary the meter reading and the use of the adjustable injector, which is operated by means of a hand wheel, avoids excessive use of motive water at low capacities.

The chlorinators have an individual meter ratio of 20 : 1 and are available in models giving a flexible range of operation from a minimum of 2.5 to a maximum of 350 lb./hr. of chlorine.
**CPE 1566**

Beryllium monitor

In conjunction with the U.K.A.E.A., Plessey Nucleonics Ltd. have produced a portable radiation monitor, designed for comfortable transportation by two men, capable of detecting beryllium in an aggregate containing less than 0.01% BeO.

A gamma source housed in the equipment irradiates the sample and neutrons subsequently released by the beryllium are slowed down in an oil tank where they are detected by proportional counters.

Transistorised, shockproof and impervious to extremes of temperature and humidity, the equipment is powered by eight dry cells stored in the monitor. The sensitivity is such that 0.004% BeO doubles the normal background rate.

Two adjustable carrying handles are fitted to the instrument to ensure that the operators are not over-exposed to irradiation. Shielding is also provided within the equipment and a display unit is mounted in a position convenient for one of the operators.
CPE 1567
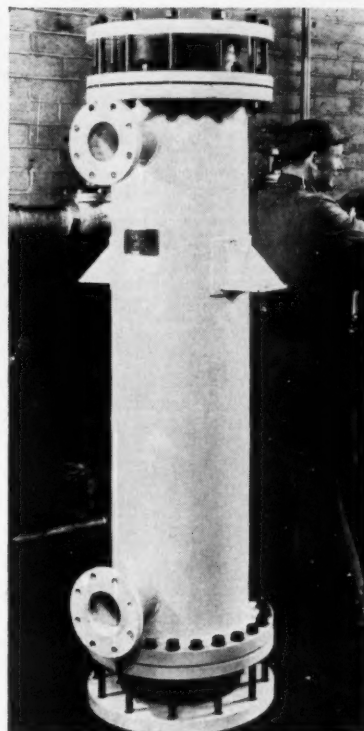
Graphite cartridge condenser.

Cartridge condenser

A new graphite cartridge condenser has been added to the range of *Delanium* graphite heat-exchange equipment of Powell Duffryn Carbon Products Ltd.

The graphite element or ' cartridge ' is cylindrical in form and is equipped with through-holes along the major axes down which the condensing vapour passes. The service fluid passes in counter-flow through the annular space between the robust steel jacket and the slotted outer surface of the graphite cartridge. Carbon inlet and outlet heads complete the assembly.

The steel jacket may be lined with suitable inert materials if service fluids other than water are employed. Strong mounting lugs are provided which enable the unit to be easily and quickly installed on site by bolting directly to a wall or to convenient steelwork. **CPE 1568**

Air compressors

G. & J. Weir Ltd. are to manufacture *Isotemp* packaged centrifugal air compressors, designed by Clark Bros. Co. Designed in seven frame sizes with capacities ranging from 5,000 to more than 50,000 cu.ft./min., the new compressors will provide primary 110 p.s.i. air for tonnage oxygen plants and other industrial uses.

A feature of the compressor is the system of integral intercoolers, which are built into the base of the machine to form a compact, unit-engineered package. Efficiency over a wide operating range is said to be produced by intercooling between stages and the utilisation of closed-type impellers and volute diffusers. **CPE 1569**

Computer for process industries

An analogue computer designed for the process industries is offered by de Havilland Propellers Ltd. This computer, *Anatrol*, can monitor and control manufacturing processes such as the production of petroleum, oil, chemicals and food liquids.

Among the advantages claimed for the installation of this computer are that the quality may be varied at will, and efficient operation at varying rates of output can be achieved.

The formula for the operation of the plant is stored in *Anatrol* as a mathematical model, by means of a number of equations which form the programme of the computer. The state of the plant and the materials flowing into it and through it are made known to the computer by signals fed into it from measuring instruments. With a knowledge of these equations and measurements, *Anatrol* is able to determine and adjust the control settings required for the plant to operate at peak efficiency. Measurement calculation and any necessary control changes proceed continuously. **CPE 1570**
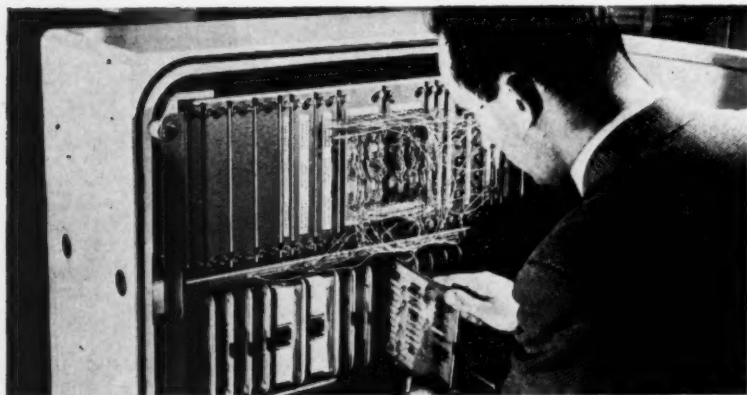
On-line process control computer. The operator is seen here inserting a printed circuit card into the arithmetic unit, which is housed in the lower part of the cabinet.

Cathodic protection

Cathodic protection is playing an increasingly important part in preventing corrosion on external hull surfaces, and recent developments in this field are meeting with considerable success. One of the problems involved in the ' sacrificial anode ' system of cathodic protection is finding a mounting material for the magnesium anode which not only provides good insulation but also has strong corrosion - resistant properties. A material claimed to overcome this problem is a grade of densified wood laminate, developed for this application by Permali Ltd.

During prolonged tests, the magnesium anode was mounted on a *Permali* block and the complete assembly was then placed at the low-water mark of sheet piling in Birdham Pool. Periodic inspection to ensure that the anode was working against the sheet piling showed the *p*H of deposits on the mounting to be nine.

This assembly was left in position for nearly two years, and finally removed when the anode had been completely consumed. At the first inspection no sign of any degradation was found on the mounting, and further laboratory tests which were carried out showed that the blocks were still above their guaranteed minimum values even after two years' arduous duty.

Insulation resistance measurements which were made between the holes in the panel showed values ranging from 90 to 227 Megohms. After the whole panel had been immersed in water for a further 24 hr. and then retested, the insulation resistance had dropped to 0.2 to 0.5 Megohms. **CPE 1571**

Thermal expansion problems

Among the problems facing the designers of atomic power stations is the one of accommodating the considerable thermal expansions of the ducting conveying the coolant gas from the reactor to the heat exchangers.

A new type of restraint has been developed by Richardsons Westgarth & Co. Ltd.

It works entirely on elastic deformation principles. A multiplicity of high tensile bars, arranged in two groups into two frusto-conical assemblies, and spaced uniformly around the periphery of the duct, transmit entirely uniformly the axial forces. In the axial direction the joint behaves as a stiff connection, but it can deform angularly by transverse bending of the bars. The deformation of the restraint is achieved by pure elastic deformation of the restraint bars, so that the forces involved are both accurately predictable and not variable in time. The rotational symmetry of the restraint makes it equally flexible in any direction.

A wide range of working deflections and restoring moments can be accommodated by varying the basic dimensions of the restraint, the number and size of the tie-bars, and the cone angle.
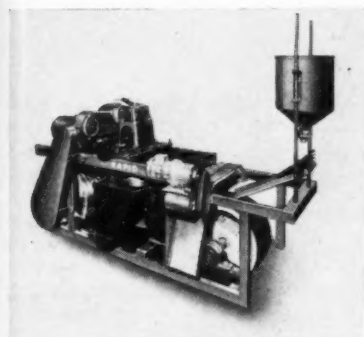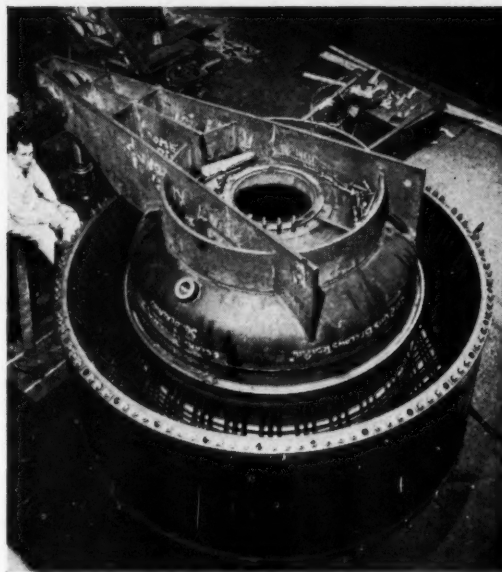
A centring device connecting the two duct stub ends ensures that no torque loading can be applied to the convolutions and equalises the deflections of the two sets of bars under conditions of steeply changing bending moment along the duct. The shear force accompanying such a change of bending moment is taken entirely by this device, leaving the bellows free of this additional loading. A further advantage of the design is that the completely transparent and accurately calculable stress system allows a close approach to an ideal shape in the tension bars.

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approximating constant stress distribution along the length of the bar, and selected numbers undergo individual fatigue tests on a specially built rig as a final quality check. Apart from the bellows convolutions, the tension bars are the only components of the restraint which are subjected to appreciable stresses and, in addition to the theoretical advantages mentioned above, it is of obvious benefit to be able to use for such components highest-quality steels and most stringent manufacturing controls. This is made possible by the fact that a multiplicity of bars is used and that they are not welded to the main duct structure. **CPE 1572**

Full-scale test rig of the expansion joint on which the required fatigue tests have been carried out.

Single disc magnetic separator.

This sectioned 'Worcester' valve shows the ball-valve principle of operation, the method of sealing and the detachable pipe flange ends.

Ball valve

A new ball valve is offered by the Worcester Valve Co. Ltd. It is available in sizes $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$ and 2 in. in bronze, carbon steel and stainless steel and with a wide range of seating materials such as Buna-N, nylon and PTFE. The makers say it can be used to replace gate, flange gate, diaphragm and lubricated plug valves.

The valve serves both as valve and union. Designed with detachable pipe ends which replace companion flanges, the valve is serviced by removing four nuts, sliding out the four bolts and the entire centre section lifts out. **CPE 1573**

Magnetic separator

A single disc unit, which treats granular free-flowing minerals such as garnet, monazite, ilmenite, wolfram, columbo-tantalite, etc., and incorporates a magnetic scalper prior to the disc which removes highly magnetic minerals such as magnetite, ferro-silicon and other iron oxides, so preventing agglomeration at disc discharge, is offered by Rapid Magnetic Ltd. By mechanical adjustment of the disc and rheostatic control of magnet current, a further two magnetic minerals are separately recovered in one passing and discharged either side of the separator belt. Clean non-magnetics are discharged at the conveyor head.

Industrial applications include removal of fine iron contamination from abrasives, refractories, chemicals, dehydrated foods, etc., where a completely iron-free product is essential.

Feed is by gravity from a hopper; alternatively a vibratory unit is available. Capacity is dependent on characteristics of the material and degree of separation required. **CPE 1574**

Flow valve

A constant-flow valve, manufactured by Black Automatic Controls Ltd., is claimed to maintain automatically a constant rate of fluid flow, irrespective of variations in the supply or delivery pressures. Designed in the first place to control the flow of fuel oil and creosote pitch to open hearth and other oil-fired furnaces, it may be used with all kinds of oil-burning appliances, where a constant flow rate is essential, and with most other liquids. Where problems of corrosion arise the design enables all parts in contact with the liquid to be constructed of stainless steel or other corrosion-resistant materials. **CPE 1575**
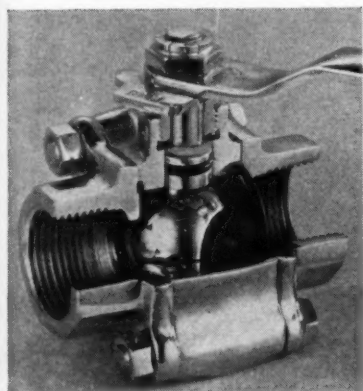
PVC sheet

To meet the need of the chemical plant and associated industries for a tough, thermoplastic sheet of excellent chemical resistance and high impact strength, Bakelite Ltd. has developed a new grade of PVC sheet, *Vybak DVR* 258.

This material is a rigid flexible composite sheet said to be particularly suitable for tank lining applications. The flexible portion gives added strength to the sheet and is more easily cemented to metal than rigid sheet. The rigid side, in its turn, has superior chemical resistance to the flexible portion.

The sheet can be sawn and drilled in machines similar to those used in the woodworking or light engineering industries, and is claimed to be easily welded by the hot gas welding technique. Due to its thermoplastic nature it is easily formed by heating to around its softening point and cooling in contact with the desired contour. **CPE 1576**

Atomic Energy in the Sixties

IT is in many ways to be regretted that atomic energy is so much in the public eye—often for the wrong reasons. The general public is sometimes under the illusion that the sole activity of the U.K. Atomic Energy Authority is weapons manufacture; completely forgetting the enormous effort devoted to fundamental research, power generation and dozens of other projects. The sixth annual report of the U.K.A.E.A.* surveys the whole sphere of activities in which the Authority is engaged at present and underlines the balanced optimism exuded by Charles II Street—in spite of the nuclear power cuts proclaimed not so long ago.

During the past year the Prime Minister announced the transfer of ministerial responsibility for atomic energy matters from himself to the Minister of Science (Lord Hailsham). This differentiates the U.K.A.E.A. from other nationalised industries, only indirectly under ministerial control. It remains to be seen whether it was wise to appoint a Minister of Science who is a lawyer by profession (the converse—appointment as Lord Chancellor of a professional scientist would, of course, never be envisaged). One gains the impression from this report that the chief executives (the atomic knights) of the Authority are supremely gifted and capable planners who, although not clad in armour, are as (intellectually) chivalrous as the knights of ancient fame.

Uranium production

The report states that during the past year the output of fissile material rose by 40% and of electricity by 300%. A large part of the new Springfields uranium processing plant was completed during that year. In the original concept is was decided to use a new method involving fluidisation techniques for converting uranium nitrate into tetrafluoride. It is intended that this process should be continuous and

*United Kingdom Atomic Energy Authority. Sixth Annual Report, 1959-60. H.M.S.O., 5s. net. Pp. 72.

therefore much cheaper; with this in mind a full-scale prototype unit was erected. This unit is now producing uranium tetrafluoride of good quality at the design throughput. Reactor operating procedures have been improved significantly resulting in increases in both availability and rating.

Reactor development

The objectives of the reactor development programme are stated by the report to ensure the successful construction and operation of nuclear power stations now under construction. (A list of the Authority's reactors in operation up to April 1960 is shown in Table 1.) Besides this, of course, advanced reactors must be developed to provide progressively cheaper power. Such development falls into two parts. The first envisages reactors with low capital cost obtained with the aid of slightly enriched fuel; here the Authority has concentrated on the advanced gas-cooled reactor (A.G.R.). A prototype A.G.R. is under construction at Windscale and should be completed by the spring of 1961. The second stage is the development of reactors having both low capital costs and small net consumption or a net gain of fissile material, such as the fast-breeder and high-temperature gas-cooled reactors (H.T.G.C.).

As far as fast-breeder reactor systems are concerned much experience has already been gained from the Dounreay reactor which became critical in November 1959, and is to be gradually worked up to full output. A prototype power-producing fast-reactor may be built for operation by 1967; the development of this should enable a commercial power station to be specified. The DRAGON project, a joint venture under the auspices of the O.E.E.C., is an attempt to reduce power costs by going beyond the limitations of A.G.R. It will initially operate with highly enriched

The interior of one of the radiation cells at the Wantage Radiation Laboratories which are part of the Harwell isotope division.
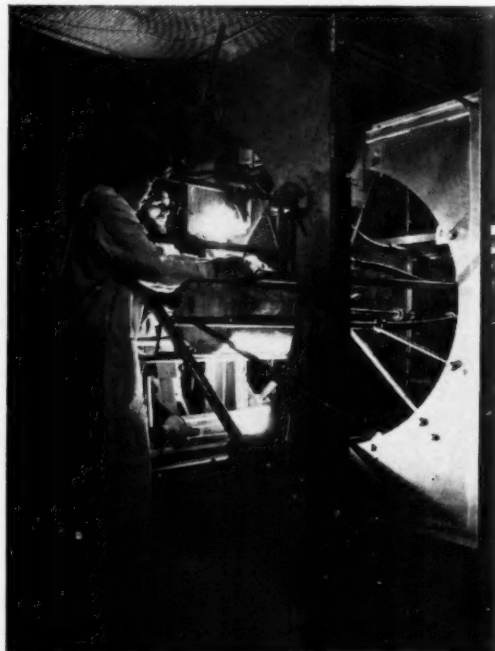
uranium as fuel and thorium as fertile material. The zero energy reactor ZENITH which was designed to support the work on the H.T.G.C. DRAGON project was completed during the last year.

Nuclear technology research

Since radiation is capable of causing physical and chemical changes in materials, stability under radiation is important for materials in reactors and fuel processing plants. Much work has been carried out at Harwell during the past year in connection with the problem of radiation damage. Thus, in recently constructed chemical extraction plants, the solvent system tributyl phosphate in kerosene was used. A study of the radiolysis of tri-alkyl phosphates showed that in addition to hydrogen and light hydrocarbons, dialkyl and smaller amounts of monoalkyl phosphoric acids are produced. The radiation yields were found to decrease steadily on passing from the tri-methyl to the tri-butyl ester. This work provided a good basis for understanding the role of solvent decompositions at critical points in the past.

Radioisotopes

Work has continued at Wantage on the industrial applications of radioisotopes. The method of fluorescence spectroscopy using radioactive sources has been applied to measuring very thin surface coatings. Instruments based on this and a related technique have been used industrially to measure metal coatings about ten-thousandths centimetre thick. Radioactive tracers also continue to be applied in new ways. Thus in the electroplating industry the action of some additives used to brighten and level plated deposits have been elucidated with the help of tracers. A pilot plant for irradiating packages of materials with gamma rays has been built at Wantage to use, initially, 120,000 curies of cobalt-60. Most of the capacity of this plant is reserved for sterilisation by manufacturers of medical equipment, for clinical trials and for packaging and storage tests before full-scale production.

Raw materials

It was pointed out that the Authority's commitments under their long-term contracts are now greater than their immediate requirements and for many years they will have to hold larger stocks than they need. This is partly due to the slowing down of the nuclear power programme as well as reductions in initial uranium loadings, which
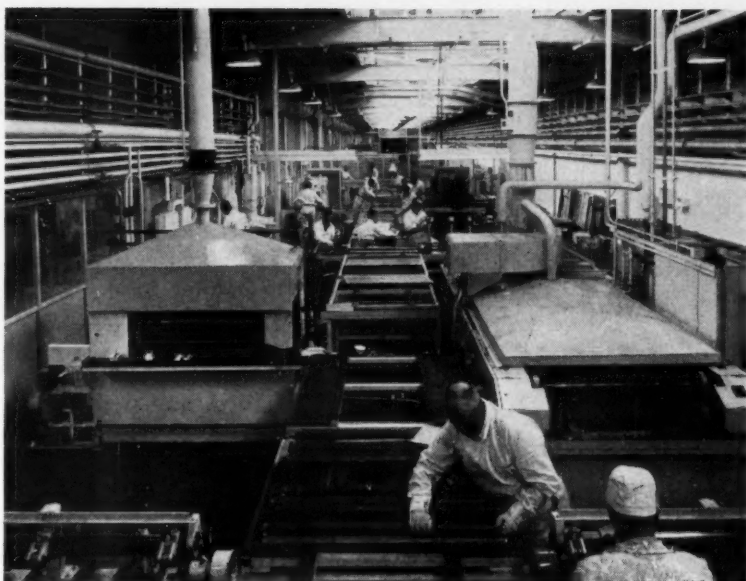
The finishing end of the fuel element canning line at Springfields.

Loading a fuel element into the ZENITH reactor which is being used initially to obtain data for the DRAGON project at Winfrith.
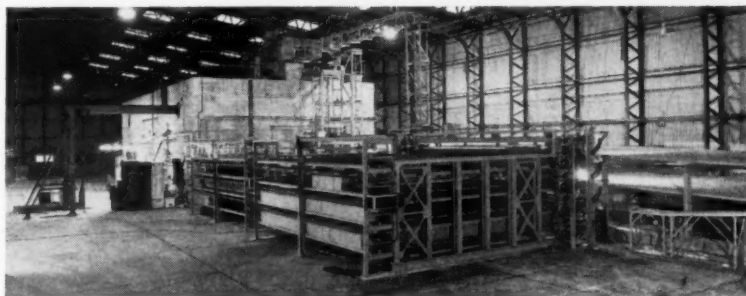
General view of the package irradiation plant and storage racks at Wantage.

Table I. U.K.A.E.A. reactors

Name	Location	Date of start-up	Maximum heat output	Moderator	Coolant	Fuel
(1) GLEEP	Harwell	1947	100 kW.	Graphite	Air	Nat. U and UO_2
(2) BEPO	Harwell	1948	6 MW.	Graphite	Air	Nat. U
(3) DIMPLE	Harwell	1954	100 W.	Heavy water	None	Varies
(4) LIDO	Harwell	1956	100 kW.	Light water	Light water	U^{235}
(5) DIDO	Harwell	1956	10 MW.	Heavy water	Heavy water	U^{235}
(6) PLUTO	Harwell	1957	10 MW.	Heavy water	Heavy water	U^{235}
(7) D.M.T.R. (PLUTO type)	Dounreay	1958	10 MW.	Heavy water	Heavy water	U^{235}
(8) HORACE	Aldermaston	1958	10 W.	Light water	Light water	U^{235}
(9) Fast reactor	Dounreay	1959	60 MW.	None	Sodium potassium alloy	U^{235} and Pu
(10) ZENITH	Winfrith Heath	1959	100 W.	Graphite	None. Nitrogen used as heating gas	Ceramic elements containing enriched uranium oxide
(11) HERALD	Aldermaston	1960	5 MW.	Light water	Light water	U^{235}
Research and experimental reactors under construction						
(12) AGR	Windscale	1961	100 MW.	Graphite	Carbon dioxide	Enriched uranium oxide
(13) HERO	Windscale	1961	A few Watts	Graphite	Carbon dioxide (used as heating gas)	Enriched uranium oxide
Research and experimental reactors of which construction has been approved						
(14) NESTOR	Winfrith Heath	Dec. 1960	10 kW.	Light water	Light water	Enriched uranium-aluminium alloy
(15) HECTOR	Winfrith Heath	Mid-1962	Up to 100 W.	Graphite	Carbon dioxide (used as heating gas	Permanent fuel: enriched uranium-aluminium alloy. Central core: Variable
Plutonium/power-producing reactors (in production)						
(16-19). Calder (two stations) ('A' and 'B') (four reactors)	Calderbridge	Station 'A,' 1956 Station 'B,' 1958	200 MW. per reactor (37 MW. (E) net)	Graphite	Carbon dioxide	Nat. U
(20-23) Chapel-cross	Annan	1958 (first reactor) 1959 (reactors 2, 3 and 4)	200 MW. per reactor (37 MW. (E) net)	Graphite	Carbon dioxide	Nat. U

Note.—ZEUS was dismantled in September 1957. ZEPHYR was dismantled in June 1958. HAZEL was dismantled in September 1958. NERO was dismantled at Harwell and is to be re-erected at Winfrith in 1960. NEPTUNE ceased operation in June 1959.

have resulted from design improvements in the Magnox reactor. As a result of the announcement by the U.S. Atomic Energy Commission in November 1959, that its options on Canadian uranium would not be taken up after expiry of the current contracts in 1962 to 1963, proposals were worked out between the U.S.A.E.C., Eldorado Mining and Refining Ltd., and the Authority to spread the current contracts over a longer period, in some cases up to the end of 1966. This should save the Canadian mining industry which has been built up with such great effort.

Health and safety

The main potential health problems arise from waste disposal of radioactive materials. The report states that the Authority is carrying out both short-term development as well as long-term research into this subject. It is felt that the ultimate solution to this problem may well be storage of waste material in special glasses which would be buried underground. This work is going on in close association with the International Atomic Energy Agency which is preparing regulations for the safe transport of radioactive materials.

Commercial operations

The Authority's revenue during the year amounted to almost £20 million, made up of sales mainly from fuel elements for the civil power programme, radioisotopes, graphite and electricity as well as various services such as consultancy and training. Manufacture of radioactive isotopes for civil purpose seems to be a very profitable undertaking; the sales of these isotopes came to a total value of £1.1 million during the last year. Medical uses accounted for half the total of 35,000 deliveries, about 15% went to industry, and the remainder to various research facilities. The estimates for 1960-61 provide for a net expenditure of £93,293,000, compared with £92,433,010 for 1959—an increase of only £860,000.

Conclusions

Altogether, it may be said that the Authority has accounted well for its activities. It must be remembered that the U.K. has more nuclear installations than any other country in Europe (except the U.S.S.R.) and its responsibility as leader in the Western European nuclear championships prevents it from undertaking some of the bolder and more hazardous projects which are being planned by the Euratom group. Sir Roger Makins, the chairman of the U.K.A.E.A., has repeatedly stressed that this country could not afford to experiment with other types of power reactors; implying that unless a country had the financial resources of either the United States or the Soviet Union, such diversification would yield no useful results. The Euratom countries do not share this view, and although not a single nuclear power station is at present in operation in any of those countries, considerable experimentation with different systems is being undertaken. The future only will show who was right.

But it must be hoped for the sake of this country that our atomic knights gambled wisely when they placed our shirts on the gas-cooled graphite-moderated system.

Separators. A booklet has been issued by William Boulton & Co. Ltd. on gyratory separators. The separators are recommended for a large number of industries including the chemical and petroleum industries.

Conveyor belting. A catalogue dealing with conveyor belting details the range of natural and synthetic fibre rubber-covered conveyor belts available from Turner Bros. Asbestos Co. Ltd. In addition there is information about conveyor belt installation, operation and maintenance.

COMICAL ENGINEERING CORNER
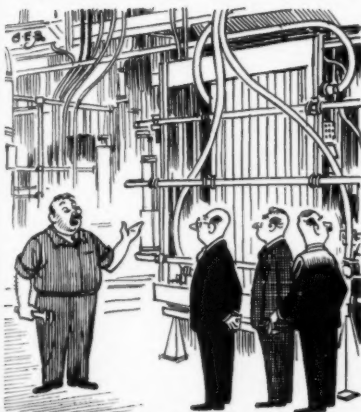
'TURNS SALT WATER INTO DRINKING WATER, IT DOES — WHATEVER THAT MAY BE'

Of interest to our readers . . .

A number of articles appearing in our associate journals this month will appeal to readers of CHEMICAL & PROCESS ENGINEERING.

Manufacturing Chemist—Market Research in the Chemical Industry, by G. Allen. Ashburton Chemical Works—opening of new laboratory. Laboratory Waste Systems in Borosilicate Glass, by Barrett and Curry.

Paint Manufacture — Carbon Black Dispersions, by P. Lowe. Dispersion of Micronised Pigments with Impeller Equipment, by W. G. Wade and B. A. Taylor. Micronisation of Titanium Dioxide, by A. E. Williams. Silicones in Hammer Finishes, by P. A. Griffin.

Petroleum—Special 21st anniversary issue. Twenty-one Years of Petroleum Reporting. Development of Refinery Engineering in Europe and the U.K., by E. F. M. Tait. Insulation in the Petroleum Industry. Rubber-lined Pipework.

Automation Progress—Millimicrosecond Computing, by A. St. Johnston and N. E. Wiseman.

Food Manufacture—Processed Foods for Cats and Dogs, by W. R. Wooldridge.

Corrosion Technology — Corrosion-resistant Cements and Their Applications, by V. Evans. Review Symposium on Protection of Gas Plant and Equipment from Corrosion.

Fibres and Plastics—Analysis and Testing of Plastics, by G. V. Ives.

CORRESPONDENCE

Brighton Symposium

SIR—At the recent Distillation Symposium in Brighton, organised by the Institution of Chemical Engineers and the Chemical Engineering group of the Society of Chemical Industry, only two papers dealt with the practical determination of vapour-liquid equilibria. An excellent survey of thermodynamic methods for interpreting vapour-liquid equilibria by Prof. Ellis and Dr. Bourne showed that a good deal more experimental work, particularly on ternary systems, is required to check on the calculated equilibria.

It seems to the writer that this is an important point. In the final analysis the designer depends on the vapour-liquid equilibrium figures available for the system under consideration. Distillation techniques have advanced so far that we are in danger of forgetting the basic vapour-liquid equilibria. There is no doubt that a good deal more work on this is still necessary.

M. G. PERRY.
Department of Fuel Technology
and Chemical Engineering,
University of Sheffield.

Trade associations

SIR—As a regular reader of your journal I should like to mention an occurrence which in my opinion warrants careful consideration. Recently, I moved into a new apartment fitted with baths, hand basins which appear to have attraction for scum which is left behind after use. From my knowledge of surface chemistry I assume that this is entirely due to the quality of the manufactured soap. However, since the adhesion of scum in this case was far greater than I had normally experienced, I concluded that it must also have something to do with the nature of the paint, etc.

Upon querying the suppliers of this equipment the advice offered was to use a certain product as cleaning agent. Finding it impossible to obtain this product in the ordinary supply, I was recommended to go to a builders' merchant, but it is somewhat unusual to refer to a builders' merchant. I am beginning to feel such new trade associations, i.e. manufacturers of enamel equipment, the suppliers, the builders' merchant and others all seem to be in league to deceive the public, what do your other readers feel?

S. G. ROBINSON,
London, S.W.15.

Nuclear Notes
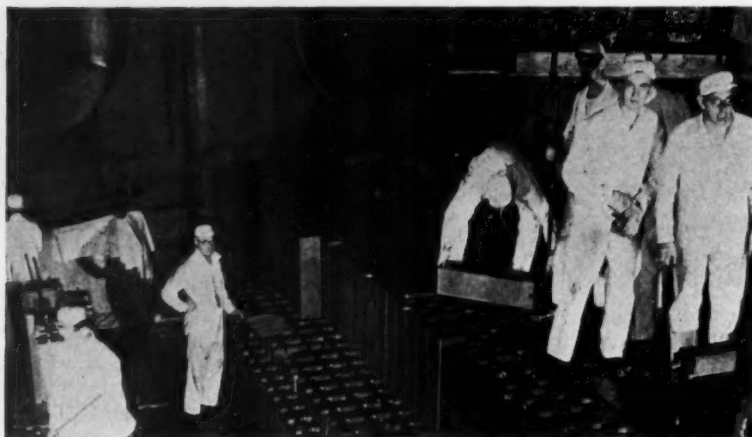
BERKELEY POWER STATION

Graphite laying of the core in No. 1 reactor has now been completed at Berkeley nuclear power station. The photo shows graphite laying near to completion as can be seen from its height relative to the gas ducts in the background.

Asia's biggest reactor

The largest atomic research reactor in Asia, the Canada-India reactor erected at a cost of £7.5 million at Trombay, near Bombay, has reached criticality. The reactor is loaded with a complement of 183 fuel elements, about half of which were fabricated in India from Indian uranium and the other half supplied by Canada.

The reactor's capacity is said to be four times that of the reactor built by China with Soviet aid. By January it is expected to produce its maximum rated capacity of 40 MW.

Cloud chamber

The European Organisation for Nuclear Research (C.E.R.N.) is building a 150 cm. cloud chamber, equipped with a magnetic field, which should be completed about the end of this year. The cost of construction and operation, staff and material included, is estimated at 3 million Swiss francs.

Federal Institute of Technology, Zürich (E.T.H.), wishes to co-operate in the construction of this machine and in the experiments undertaken by the cloud chamber group. The agreement between C.E.R.N. and the E.T.H. stipulates that representatives of both parties will participate in the building of the apparatus. Once finished, this cloud chamber will re-main their joint property for two years; scientists from C.E.R.N., from E.T.H. and from other member states will operate the chamber.

The cloud chamber is an experimental apparatus associated with the operation of accelerators. Particles going through it leave tracks inside the chamber; these tracks can be photographed and allow subsequent study of the nature and behaviour of the tiny 'grains' of matter.

HECTOR for Winfrith

The U.K.A.E.A. has appointed Fairey Engineering Ltd. as the major contractor for the design and construction of a new zero-energy nuclear reactor to be erected at its Winfrith Heath establishment in Dorset. Known as HECTOR, it will be used to reproduce and study the nuclear properties of different designs of power reactor.

It comprises, in effect, a small reactor core which can represent the core of any type of power reactor, within a larger conventional reactor which 'drives' that under test. It is believed to be the first reactor in the world in which different reactor core designs can be studied under such a wide range of experimental conditions. It will also be used to study the nuclear properties of new atomic fuels such as plutonium, thorium, uranium-233 and ceramic fuels.

Among the samples which will be tested will be irradiated fuel elements discharged from other experimental and power reactors; it will be possible to study their nuclear properties after long burn-up periods.

I.A.E.A. training programme

The U.S.A. has offered 80 cost-free fellowships to the International Atomic Energy Agency (I.A.E.A.) for its 1960 training programme. The offer brings the total of the cost-free fellowships offered for the programme to 225 fellowships.

Through this training programme, to which I.A.E.A. has given high priority since its inception, advanced students, engineers, chemists, biologists, research workers and other specialists are trained in various aspects of the peaceful applications of atomic energy.

At present 272 I.A.E.A. fellows are studying at universities and institutes in 28 member countries. Since the programme started in 1958 a total of 101 fellows have completed their studies and a further 378 from 36 countries have been selected by the International Atomic Energy Agency for training under its 1960 programme.

Halden project

The duration of the O.E.E.C. Halden reactor project in Norway has been extended by 1½ years in addition to the original three years. The project is one of the O.E.E.C. European Nuclear Energy Agency's three joint undertakings. The reactor, which first went critical in June of last year, is the only one of its type in the world.

Corrosive-liquid pump

Hydrofluoric acid is handled in ton quantities each day by the U.K.A.E.A. in its uranium refining operations.

Improvements in these operations have brought many new problems, not the least of which have been those associated with the pumping of this intensely corrosive material.

Capenhurst engineers of the Authority's development and engineering group have devised and tested a rotary pump for operation in hydrofluoric acid. A feature of the pump, which operates from above the vessel, is its

arrangement of a long hollow shaft with bearings self-lubricated by an enclosed oil circuit. The shaft constitutes the oil container and bearing housing, and operation of the pump for long periods of time without maintenance is expected.

A continuous flow of nitrogen gas from a low-pressure supply prevents hydrofluoric acid vapour from diffusing into the working parts, and also ensures that oil vapour from the lubricant does not contaminate the liquid being pumped.

The system is apparently more complex than one which would have an external motor at the bottom of the vessel driving the impeller by a shaft passing through a seal. But this solution has been rejected because of the difficulty of providing material which will resist corrosion and maintain a satisfactory leakproof seal.

Overhaul of GLEEP

GLEEP, Western Europe's first reactor, has received an extensive overhaul after being in use at A.E.R.E., Harwell, for nearly 13 years. This modernisation will increase the safety and efficiency of the reactor and will enable it to give valuable service for many further years.

It is an air-cooled graphite-moderated reactor which gets its name from graphite low-energy experimental pile.

During the shut-down the reactor instrumentation was completely re-

EQUIPMENT FOR NEBRASKA

Four massive pieces of nuclear equipment towards the end of their journey from the Philadelphia area to the Hallam, Nebraska, nuclear plant site. The photograph shows a barge containing the 80-ton reactor vessel, 65-ton containment tank, 13-ton upper cavity liner ring and 4½-ton upper thermal shock liner ring being edged into a landing on the Missouri River near Plattsmouth, Nebraska. The 75,000-kW. Hallam nuclear power facility, being built for the U.S. Atomic Energy Commission, will utilise a sodium-cooled, graphite-moderated reactor designed by Atomics International.

newed. The two previous control rooms, one for the reactor and one for the experimental facilities, have now been combined in one entirely new control room which commands an extensive view of both. Most of the new instrumentation is conventional, although the opportunity has been taken of fitting transistorised linear and deviation amplifiers.

The reactor is used principally for materials testing, making use of an oscillator which takes small samples rapidly from the edge of the pile to the centre and back again. The resultant fluctuation of power level is measured and the slow neutron absorption cross-sections of different materials compared.

Radio-frequency liner

A further stage in the development of the site of NIMROD, the giant synchrotron, which is being built next door to Harwell, was reached when work was completed on the first radio-frequency liner for the injector accelerator. This is the first liner of its type to be produced in this country and will be installed soon on the NIMROD site, which in turn will be the centre piece of the new Rutherford high-energy laboratory of the National Institute for Research in Nuclear Science.

The firm who were entrusted with the manufacture of this highly intricate piece of equipment is the London Aluminium Co. Ltd. The job of the radio-frequency liner will be to accelerate protons from 600 KeV to 15 MeV.
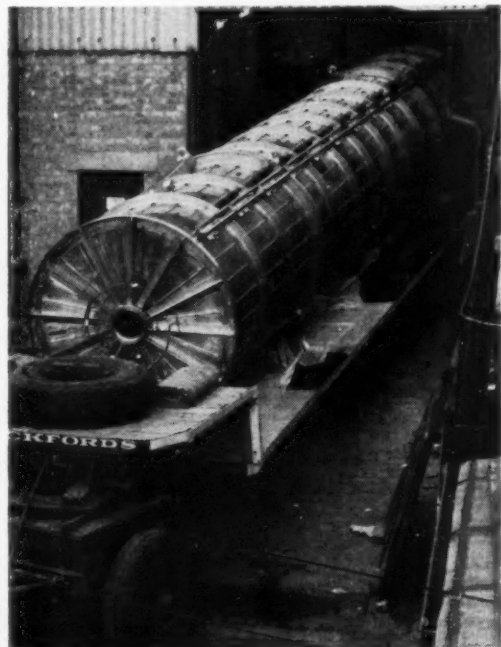
Just about to set off on its journey to Harwell from Witton is the radio-frequency liner which took 12 months to build.

New Books

Handbuch der präparativen anorganischen Chemie. Second Edition. Vol. I. Edited by Georg Brauer. Ferdinand Enke Verlag, Stuttgart. 1960. Pp. xiii + 884. Paperback DM 118. Linen covered DM 124.

The inorganic section of Vanino's well-known ' Handbuch der präparativen Chemie' was replaced after the war by the first edition of this book, edited by Prof. R. Schwarz. The task of editing the second edition has been undertaken by Prof. G. Brauer, though its various sections have been contributed by 14 specialists, each well known in his own field. The completed work will contain a description of the majority of inorganic preparations which are important from a purely scientific viewpoint or because of potential technical interest. An important qualification, however, is that compounds available commercially, or which can readily be prepared by familiar methods, are omitted. One is thus left with what may be described as the cream of the subject —compounds with considerable inherent interest and which, for the most part, involve special and often unfamiliar procedures in their preparation. Many of the methods have been checked in the contributors' own laboratories and, when this is not the case, they appear to have been selected with regard to the reliability of the original publication.

The first chapter of some 100 pages gives a very useful review of special techniques, such as the vacuum manipulation of gases, the measurement and control of high and low temperatures and standard purification procedures. There is also a good review of ceramic materials suitable for inorganic work. No reference is made, however, to physical techniques, such as gas-phase chromatography and infra-red spectroscopy, which are now very commonly used as a control of purity. The bulk of the first volume deals with the preparation of a wide range of compounds of A-group elements (H, F, Cl, Br, I, O, S, Se, Te, N, P, As, Sb, Bi, C, Si, Ge, Sn, Pb, Al, Ga, In, Tl and the alkali and alkaline earth metals). There are about 1,000 preparations in all, and a summary of properties and suitable literature references are given for each of the compounds selected. About

1,000 line diagrams are also included. Some idea of the type of compound dealt with may be gathered from Dr. Kwasnik's chapter on fluorine and its compounds, where one finds the halogen fluorides, a range of oxyfluorides of non-metals, higher fluorides of the transition metals and a number of fluorocomplexes—some 140 compounds in all. It is interesting that Ruff's old method is given for the preparation of vanadium pentafluoride instead of the more satisfactory direct fluorination of the metal. The excellent preparation of nitryl fluoride by the action of fluorine on sodium nitrite is also missing. Prof. Fehér, writing on sulphur, selenium and tellurium, includes many unfamiliar substances such as the hydrogen polysulphides, the chlorosulphanes and sulphur nitride and related substances. Similar examples could be quoted from the other chapters. They all describe a most impressive array of modern work, much of which has not been described before except in the original literature. It is convenient to have it collected in this way as one could otherwise overlook some of the many and varied methods which are now available.

The usefulness of a book such as this in university teaching laboratories is, unfortunately, restricted by the very small amount of time given to preparative inorganic chemistry, and also by the poor facilities which are as a rule available. This is regrettable because organic preparations offer a more limited range of techniques. Well-planned inorganic preparative work holds the interest of the student, and also helps to make analytical chemistry of greater interest if a student can analyse his own products. It is to be hoped that preparative inorganic chemistry will soon come into its own in teaching, and when this happens Professor Brauer's book will be extremely useful. There is, however, no doubt as to its value to the research worker and in certain industrial laboratories. As a reference book it makes available selected methods for preparing a wide range of somewhat inaccessible substances. Even more important, it gives a broad picture of what can now be done with refined techniques, many of which are applicable to problems quite distinct from the preparation of a particular compound.

The book also has the merits of being very well produced and documented. The contributors have earned the gratitude of all inorganic chemists for completing the first stage of this formidable task; their next volume, which can hardly fail to contain an equally interesting array of compounds, will be awaited with great interest.

H. J. Eméleus,
Professor of Inorganic Chemistry,
University of Cambridge.

Radioisotope Laboratory Techniques. Second Edition. By R. A. Faires and B. H. Parks. George Newnes Ltd., 1960. 25s. net.

Dr. H. Seligman, in an introductory preface to this book, has pointed out that many publications have appeared recently dealing with the uses of isotopes in different fields. It cannot be denied that isotopes are very fashionable both to the scientist and the layman—this may partly account for the profusion of books on the subject. The danger in saturating a subject with too many publications is that repetitions must, sooner or later, occur. However, the authors, who have both been closely associated with the Harwell Isotope School for many years, have avoided this to a large extent by concentrating mainly on the uses of isotopes and isotope laboratories. Unfortunately, they have often resorted to stating the self-evident as, for instance, on page 50 where we are informed, in connection with selection of lighting in an isotope laboratory, that ' the main considerations are adequacy, convenient disposition in relation to benches and accessibility for cleaning and replacement without radioactive hazard ' or, it is stated that ' the main hazards in a laboratory are not fire and electric shock, but carelessness and stupidity ' —something so self-evident to even first-year students that it would bore them on repetition!

Nevertheless, these shortcomings should not detract the reader from the otherwise excellent standard maintained throughout. The first chapters are devoted entirely to a presentation of the fundamentals of radiation and health physics—the chapter on health physics having been rewritten since the first edition in 1958 and taking into account the international recommendations on radiological protection. The concepts used have been clearly defined throughout, and this in itself is quite a unique achievement nowadays. The various tables and charts

included are most useful as, for instance on page 60, classification of nuclides according to toxicity, and on page 42, K-factors for certain gamma emitters. It might have been better perhaps if the first four chapters had been expanded and less space devoted to the remainder.

As a practical workaday guide to isotope technology for the chemist and engineer, this book should certainly prove its worth. The authors have wisely appended suggestions at the end of each chapter for further and more detailed reading, so that the reader, having savoured this *hors d'oeuvre*, may then proceed on to a more substantial main course.

I.L.H.

Zone Refining and Allied Techniques. By N. L. Parr. Newnes, London, 1960. Pp. 184. 40s.

The opening chapters are concerned with the more theoretical aspects of the solidification process in metals such as nucleation, segregation compositional gradients in solid solutions during freezing and the explanation and derivation of segregation coefficient from phase equilibrium diagrams which determines the degree of success likely to be achieved in zone refining. As zone refining is largely concerned with the removal of small quantities of impurities from a comparatively pure substance, the significance of controlled or directional solidification is described as a means of removing impurities to one end of a solidifying mass.

Molten zone refining is considered and the effect of repeated molten zone passes on the distribution and concentration of impurities. The zone levelling process, to achieve greater uniformity in impurity distribution by employing a number of reversed cycles or zone passes in alternate directions, is explained. In the more practical considerations in zone speed the efficiency of impurity removal by both horizontal and vertical methods is described. Purification by the vertical method is adopted where flotation or gravitation factors influence the removal of impurity elements and compounds differing in density from the solvent material.

A comprehensive chapter follows on the practical considerations involved in the choice of zone refining equipment such as material containment, atmosphere containment under vacuum, inert or reducing atmospheres, sources of heat for generating molten zones, temperature control

systems, travel mechanisms for moving molten zones and continuous zone refining. This chapter is adequately and admirably illustrated with schemes, arrangements and methods to amplify the text, since 'as complete zone-refining equipment is only just beginning to become commercially available, would-be users of the technique must frequently design and construct their own.' There follows a descriptive chapter on several basic working designs of zone - refining equipment which have already proved successful.

A complete chapter is given over to the manipulation of high - purity materials in the course of which the handling of the materials concerned, before and after zone refining, is considered, *i.e.* the preparation of materials for zone refining by sintering and casting and the fabrication of zone-refined materials by casting, welding and forming. The production of high-purity material in single crystal pulling techniques is described.

The chemical and physico-chemical determinations of the amount of impurity remaining in zone-refined material are dealt with briefly in a chapter which also deals with physical examination tests on single and polycrystalline substances. The physical methods of examination described are resistivity measurements, macro- and microscopical examination and electron microscopy.

The final chapter describes the properties and applications of zone-refined material in which the purity levels achieved and the possible influence of the residual impurities on the mechanical, physical and chemical proper-

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£ s d

CHEMICAL PLANT COSTS

Cost indices for the month of August 1960 are as follows:

Plant Construction Index: 181.1

Equipment Cost Index: 170.2

(June 1949 = 100)

£ s d

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ties of semi-conductors, metals and compounds are considered.

The book admirably succeeds in its two aims, namely to survey a technique which is of expanding interest to research and industry generally and to provide practical information on some recent advances in laboratory methods and equipment associated with the process. The material is logically presented, well illustrated and numerous references are available to provide further reading in more detail on specific aspects of the zone-refining process and the associated techniques. R. J. MAITLAND

Approaches to Thermonuclear Power. By R. F. Saxe. Temple Press, London, 1960. Pp. 65. 12s. 6d.

Rather more attention to the English might have made this volume into a minor classic. There are many very awkward phrases and such priceless titbits as 'shock wave will propagate into the gas' and 'two . . . forms of instability are . . . "necking" and "wriggling"' need to be seen to be believed. Apart from such weaknesses, the author has performed a miracle by making this little work a technical masterpiece and by condensing within such small compass the whole fundamental theory of thermonuclear fusion. Dr. Saxe covers, in his first chapter, reactions by which power from nuclear fusion might be obtained, and then follows with the behaviour of plasma at high temperatures. Discussing the various practical approaches, he deals with devices such as those using the linear pinch, toroidal devices and mirror machines.

Lest his readers might fall into the error of assuming that the millennium is at hand, Dr. Saxe shows that, although a continuously operating fusion reactor based only on deuterium would require an energy release of 10 to 100 W./c.c., values so far obtained are only of the order of 10^{-14} W./c.c., so that power outputs will have to be increased by a factor of one to ten thousand million million if they are to become practicable propositions. Obviously there is a long, long way to go. But one day there will come the breakthrough, and this will probably be made by scientists who are students at present. For such students, this book can be thoroughly recommended as an authoritative and interesting introduction to the subject. Dr. Saxe has produced a book which is a very worthy member of a very useful series of monographs. R. F. PAULSEN

Important application for
Vickers Strip-wound High Pressure Vessels

Personal Paragraphs

★ **Dr. J. Bell,** manager of the I.C.I. Nobel Division silicones department since May 1957, has been appointed to the division board in succession to **Mr. F. B. Wrightson,** engineering and technical director, who retired recently.

★ **Mr. B. S. Freeland** has been transferred to the staff of the chief engineer (sales) of Tufnol Ltd. for special duties in the Market Research unit. He was London Area branch manager of the company from 1935 and is now succeeded by his former deputy, **Mr. F. J. Griggs.**

★ The death occurred recently of **Mr. J. M. Rimington,** managing director of the chemical division of the Distillers Co. Ltd. till April of this year. He was one of the original employees of British Industrial Solvents Ltd., the first large-scale chemical venture of the Distillers Co. Ltd.

★ **Dr. D. Matheson** has been appointed H.M. Senior Chemical Inspector of Factories in place of **Mr. S. H. Wilkes** who retired at the end of June.

★ **Prof. C. S. Whewell,** professor of textile technology at Leeds University, has been awarded the Warner Memorial Medal. This is awarded by the Textile Institute in recognition of outstanding work in textile science and technology, the results of which have been published.

★ **Mr. J. Romney, Mr. N. E. F. Hitchcock** and **Mr. G. H. J. Simmons,** all senior executives of the Castrol research and technical departments, have been appointed as directors to the board of Edwin Cooper & Co. Ltd., a subsidiary of the Castrol group.

★ **Mr. G. Sims-Davies** has resigned his position as technical sales manager of British Oxygen Gases Ltd. and taken up an appointment as general manager of Hancock & Co. (Engineers) Ltd.

★ At the annual general meeting of the Federation of British Rubber and Allied Manufacturers **Mr. H. G. W. Chichester-Miles,** of Empire Rubber Co. and Rubber Bonders Ltd., was elected president for 1960-61 and **Mr. S. D. Sutton** of Veedip Ltd. and **Mr. C. H. M. Baker** of Firestone Tyre & Rubber Co. Ltd. were elected vice-presidents.

★ **Mr. W. H. Everard,** deputy general manager of the foundry division of Edgar Allen & Co. Ltd., has been appointed president of the British Electric Steel Makers' Guild.

★ **Dr. D. B. Mulholland** has been appointed head of the department of chemical engineering at West Ham College of Technology.

★ **Mr. J. A. Petrie** has been appointed assistant to the president of Kellogg International Corporation in London. He has been a member of the Kellogg organisation for 24 years and is assistant vice-president of the parent company, M. W. Kellogg Co., and vice-president and director of Kellogg International Corporation.

★ **Sir Leslie Gamage,** chairman and managing director of the General Electric Co. Ltd., is to retire at the end of this year. He will relinquish his executive duties as managing director immediately but will continue as chairman until December 31. He joined the company in 1919 as assistant secretary.

★ **Mr. M. E. O'Keeffe Trowbridge,** managing director of Sharples Centrifuges Ltd., has joined the board of directors of Sharples France.

★ **Mr. J. D. D. Morgan** and **Dr. L. M. Wyatt** have been appointed to the research board of the British Welding Research Association. Mr. Morgan is with the general chemical division of I.C.I. Ltd. and is chairman of the company's welding panel. Dr. Wyatt is the chief metallurgist of the Central Electricity Generating Board.

★ At a meeting of the council of the Iron and Steel Institute it was agreed to propose **Sir Charles Goodeve,** O.B.E., F.R.S., for nomination as president-elect of the institute at the autumn general meeting in November. He will succeed **Mr. W. F. Cartwright** as president at the annual general meeting in May 1961 and will thus be in office at the time of the institute's proposed special meeting in the U.S.A. in October 1961.

★ **Mr. W. Leonard Hill,** chairman of Leonard Hill Technical Group, will undertake an extensive tour of India and Ceylon in January and February 1961.

★ **Mr. H. Darnell** has been appointed a director of Workington Iron & Steel Co. and **Mr. Ward Jones** has been appointed a director of United Coke & Chemicals Co. Ltd. Both companies are subsidiaries of the United Steel Cos. Ltd.

Dr. D. B. Mulholland.

Mr. J. A. Petrie.

Sir Leslie Gamage.

Mr. M. E. O'Keeffe Trowbridge.

★ **Mr. W. H. Adams** has been appointed general manager of Head Wrightson Iron and Steel Works Engineering Ltd.

★ **Mr. J. B. Adams,** acting director general of C.E.R.N. and director of C.E.R.N.'s proton synchrotron division, has been awarded the Roentgen prize by the Justus Liebig University of Giessen (Germany). The award will be given annually for outstanding contributions in fundamental research in particle physics.
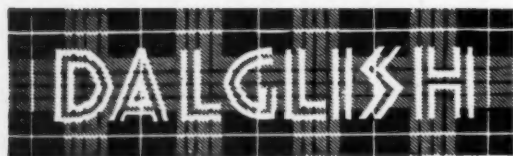
★ **Mr. L. A. Armstrong** has been appointed chief designer responsible for all pressure elements for the range of tank contents gauges, pressure and differential gauges, pressure switches and thermometers of K.D.G. Instruments Ltd.

Orders and Contracts

Computor for U.K.A.E.A.

The U.K.A.E.A. has ordered from I.B.M. United Kingdom Ltd. a STRETCH class computer.

Seventy-five to 100 times more powerful than the large-scale I.B.M. 709 which is at present in use by the U.K.A.E.A., this computer is said to perform more than 1 million logical operations/sec.

The U.K.A.E.A. system will have random access disc storage units capable of transferring one word every 8 microsec., six magnetic-core storage units with retrieval time of 2.18 millionths of a second, and a vast magnetic tape backing store.

It will be installed with the Authority towards the end of 1961.

Sulphuric acid plant

A contract to build a sulphuric acid and single superphosphate plant for Adarsh Chemicals & Fertilizers Ltd. has been awarded to Chemical Construction (G.B.) Ltd. This plant will be built at Bombay, India. It will utilise sulphur as a raw material and have a capacity of 50 tons/day. The single superphosphate plant will have a capacity of 6 to 10 tons/hr. The complete plant will commence production next year.

Unifiner-Platformer

Iraanse Aardolie Raffinage Maatschaapij (Iranian Oil Refining Co.) N.V. has awarded a contract worth $5 million to Fluor-Schuytvlot N.V., Holland (a subsidiary of the Fluor Corporation Ltd.), for the design, detailed engineering, purchasing and construction of a 20,000-bbl./day Unifiner-Platformer to be added to the refinery at Abadan in Iran.

The contract is being carried out by Fluor Engineering & Construction Co. Ltd. in London, and design, engineering and purchasing has already begun. Construction will get under way early next year. Completion is scheduled early in 1962.

Ammonia synthesis gas

P.G. Engineering Ltd. have received a contract from Tokai Ryuan K.K.K., of Japan, for the design and engineering of process plant to treat ammonia synthesis gas.

The plant is designed to deal with about 500,000 cu.ft./hr. of synthesis gas and consists of a high-pressure carbon monoxide conversion unit, using a catalyst developed by the company for high-pressure use, followed by hydrogen sulphide and carbon dioxide removal in a two-stage plant employing the *Vetrocoke* process.

The value of the contract is about £300,000.

Drying plant

The Edgar Allen & Co. Ltd. subsidiary company, Buell Ltd., has recieved an order from the Lancashire Steel Manufacturing Co. Ltd. for the supply of drying plant complete with high-efficiency dust collectors and other ancillary equipment. The plant will handle 225 tons/hr. of wet Northants. ore, containing an average moisture not exceeding 18%, to be dried to a final moisture content not exceeding 12%. Buell Ltd.'s engineers and outside erection staff are erecting this plant completely on their clients' prepared foundations. The total value of the contract is more than £200,000.

Oil-gasification plant

An order has been received from the North Western Gas Board by Woodall-Duckham Construction Co. Ltd. for a single unit reforming plant to be built at the Crewe gas works.

The new plant, which will be automatic in operation, will gasify light distillate and have an output of 2.2 million cu.ft./day of 450 B.Th.U. gas.

The installation will include a waste-heat boiler and be self-supporting in steam, a water cooling and recirculating system and a standby diesel generator to provide an alternative source of electric power.

Constructional work is to commence shortly and the plant is to be put into operation in the early autumn of next year.

Silicon rectifier for chlorine production

A silicon rectifier equipment, rated at 50,000 A at 200 V, is now being manufactured at the Chippenham works of Westinghouse Brake & Signal Co. Ltd. for Murgatroyd's Salt & Chemical Co. Ltd. at Sandbach. This equipment will be used for the production of chlorine and caustic soda by the electrolysis of brine derived from underground salt beds.

The silicon rectifier diodes will be mounted on water-cooled bus bars in four separate cubicles. The transformers, stepping down from 11 kV, and the tap changing equipment and bridging regulators to provide continuity of current control, are being supplied by G.E.C. Ltd.

Sinter machines

Head Wrightson Iron & Steel Works Engineering Ltd. have received an order from Appleby-Frodingham Steel Co. for the design and construction of further extensions to their ore preparation and sinter plants.

This order covers the supply of four additional sinter machines 8 ft. wide by 168 ft. long together with the engineering of the complete plant and has a total value of about £1.5 million.

It is anticipated that the machines will be installed and operating at full capacity by the end of 1962. They will be fabricated at Head Wrightson's Thornaby works.

Cooling towers

Head Wrightson Processes Ltd. have been awarded a contract for the supply of three induced-draught cooling towers for the new Spencer works of Richard Thomas & Baldwins Ltd.

These towers, which have a total capacity of over 1 million gal./hr. of water, will be used for supplying cooling water to the hot and cold strip mills for the finishing section of the plant. The towers will be built to a design developed by Head Wrightson and John Laing & Son Ltd. A new feature will be the *Polygrid* plastic packing.

Instrumentation for Russian works

An order covering the instrumentation for a Russian chemical works has been placed with Honeywell Controls Ltd. The £2-million plant is being built by Vickers-Armstrongs (Engineers) Ltd. to the design of Zimmers of Frankfurt and will produce chemicals used in the making of nylon.

The main contract was placed by Techmashimport of Russia early last year. This new sub-contract, worth £200,000, includes a 100-ft. semigraphic control panel containing full-size electronic and miniature pneumatic instruments for controlling temperature, liquid level, pressure and flow. Full instrumentation and installation engineering is included in the contract.

There will be 70 temperature control loops, 30 level, 30 differential pressure and 50 flow and blending loops.

Oxygen plant at steelworks

Air Products (G.B.) Ltd., in association with the Butterley Co. Ltd., have completed building an oxygen plant at Stewards & Lloyds Ltd.'s steelworks in Corby. The plant has an output of 200 tons/day of oxygen and is the first tonnage oxygen plant to be owned and operated by a steel company in Great Britain.

Gaseous oxygen is produced at a pressure of 350 p.s.i. and at 99.5% purity. Gas storage under pressure is provided for 370,000 standard cu. ft. of oxygen.

The plant incorporates the latest developments in ' low-pressure-cycle ' oxygen plant design and provides low power consumption/ton of oxygen.

Weedkiller

With the completion of their new chemical factory on the estuary of the Great Ouse at King's Lynn, Norfolk, Dow Agrochemicals Ltd. announced price reductions in *Dowpon* selective weedkiller.

The new plant stands on an 80-acre site and has cost £1 million.

It is the first stage in a project planned to become one of the largest agricultural chemical factories in Europe. Its equipment comprises a complete production plant for *Dowpon*, with ancillary services including steam, cooling water, refrigeration and air. Equipment and instrumentation is of modern design and includes corrosion-resistant materials such as stainless steel, nickel, glass and plastics.

Construction began in July of last year and the plant has been completed two months ahead of schedule by Constructors John Brown Ltd.

Nylon plant extension

To meet the expected increase in demand for nylon from the textile and plastics industries, I.C.I. Ltd. has decided to make a further addition to its production capacity for nylon polymer.

The existing plants of the company and the one at present under construction are designed for the production of nylon-66 polymer, but this latest extension, which it is estimated will cost about £10 million and which will have a capacity of about 15,000 tons p.a., will produce caprolactam, the monomer for nylon-6 polymer, not yet produced in Britain.

Catalytic reforming

A contract for the installation of an *Onia-Gegi* catalytic reforming plant at the Partington works of the North Western Gas Board has been awarded to Humphrey & Glasgow Ltd.

The plant will be built in two sections and completed in January 1962. Output is designed to be 12 million cu.ft./day of town gas, but substantial capacity will be built in.

Feedstock is refinery gas from an adjacent petrochemical works at the rate of 60,000 therms/day. Alternatively there is provision for using liquefying petroleum gases as standby.

Progress at hydro-refining plant

Two of the largest lorry-mounted cranes in the mobile lifting services division of Tarslag Ltd., one of 50 tons capacity and the other of 25 tons capacity, travelled from the Rotherham depot recently to South Wales to erect a 130-ft.-high distillation column and ancillary plant at Port Talbot.

The installation forms part of a new hydro-refining plant for the Port Talbot Chemical Co. Ltd., which is controlled jointly by the Steel Co. of Wales Ltd. and the Lincolnshire Chemical Co. Ltd. The distillation plant was designed by Lurgi of Germany, manufactured by R. & J. Dempster Ltd. and installed by Simon-Carves Ltd.

The distillation plant is in two sections—one for benzole distillation and the other for batch distillation. The raw material for the distillation plant is hydro-refined naphtha.
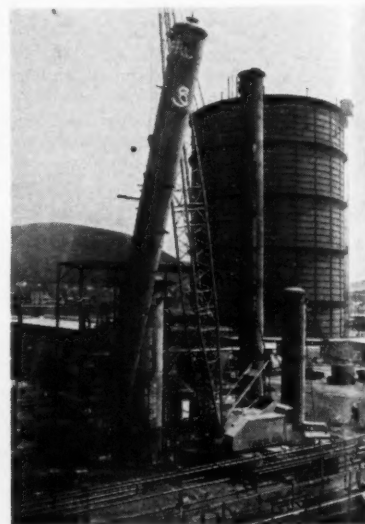

Fifty-ton lorry-mounted crane lifting the batch column on to the batch kettle at Port Talbot.

New speed gear works

Allspeeds Ltd., manufacturers of *Kopp* variable-speed gear, have moved their head office and works to Royal Works, near Accrington.

With floor area of over 120,000 sq. ft. the new works incorporate all modern services. In particular the machine shop has been laid out and equipped to enable the latest flowline production methods to be used.
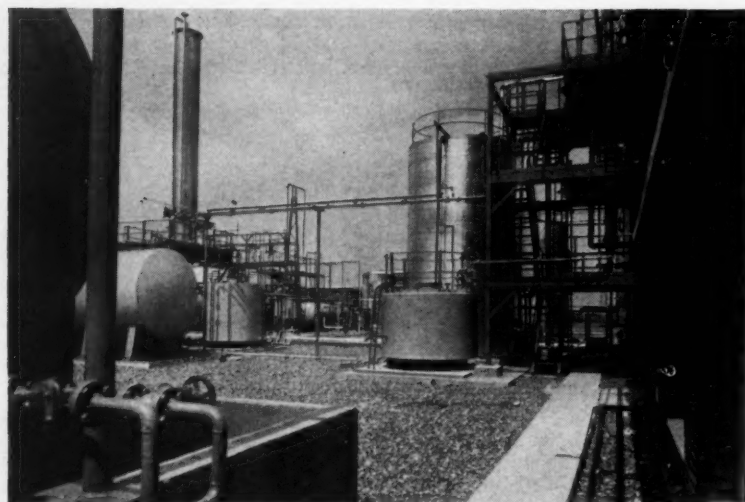
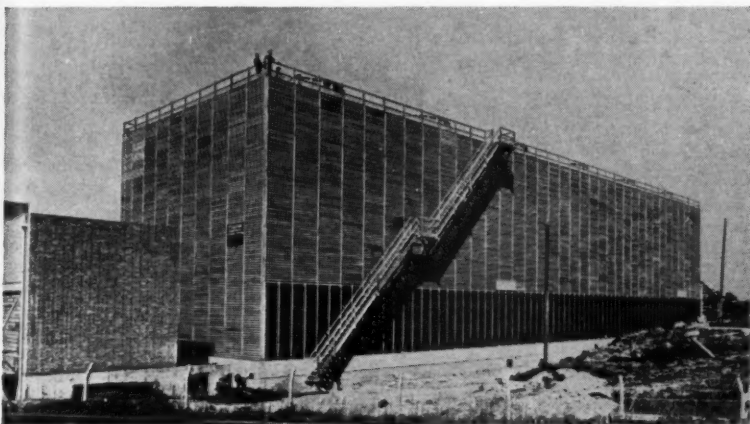View of the tank farm of the 'Dowpon' plant at King's Lynn.
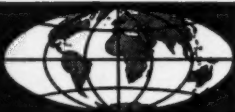
MEXICO

Cooling towers

Head Wrightson Processes Ltd. have received an order from the turbine generator division of Associated Electrical Industries Ltd. for three *Counterflo* induced-draught cooling towers. The towers, each of which consists of three cells with two 20-ft.-diam. fans, are to be installed at

A timber induced-draught cooling tower typical of the type of tower being supplied to be built in Mexico.

Cuidad Juarez, where they will each provide cooling water to one of the 3 to 33-MW A.E.I. turbine generator sets being supplied for this new power station.

Circulated to each generator set are 1,560,000 gal./hr. of water, and the towers will reduce the temperature from 89.4° to 80°F. Induced-draught towers were selected for this operation after it was found that the site available and the duty involved made them a more economic proposition than other forms of cooling equipment.

ITALY

Oxygen plant

A 380-tons/day oxygen plant is to be built at the O. Sinigaglia steelworks of Cornigliano in Genoa by Air Products Ltd. The order is valued at over £1 million.

The oxygen plant will consist of two generating units each capable of producing 190 tons/day of oxygen and storage for 560 tons of liquid oxygen, and 420,000 cu. ft. of high-pressure gaseous oxygen will also be included.

The introduction of oxygen is expected to increase the output of the company's six open-hearth furnaces from 1,102,300 to 2,094,400 tons p.a., thereby contributing an overall 90% increase to the company's production rate. Oxygen is added during combustion to increase the heat input to the furnace and is then injected through roof lances during the refining phase to speed up the removal of carbon and other impurities.

SOUTH AFRICA

Titanium oxide plant

Construction work has started on the titanium oxide plant being built at Umbogintwini on the Natal coast by South African Titan Products (Pty.) Ltd., a company formed by British Titan Products Co. Ltd. and African Explosives & Chemical Industries Ltd. This plant is expected to be completed by the beginning of 1962, will have a capacity of 10,000 tons p.a. and will cost about £3 million.

A pipeline is being laid by Collins Submarine Pipelines Overseas Ltd. along the sea-bed to discharge the factory effluent a mile out to sea at a depth of some 110 ft.

GREECE

Waste problem

The recent growth of Athens brought the tanneries of Cavada Bros. Ltd. within an inhabited area, and the firm was requested by the city hygiene department to purify the effluents from the factory before they were discharged into the sewage system.

Tannery waters contain, in addition to germs, large quantities of albumen (from the animals' blood), gelatine (from the skin), proteins and remains from tannate substances such as $Ca(OH)_2$, $NaCl$, Na_2S and Na_2SO_4.

The problem was brought to the attention of Atlas Copco Greece Ltd. who suggested the use of compressed air as a purifying medium. Two large concrete tanks each of 5,250 cu. ft. capacity were designed and compressed air mains were connected to the bottom conical orifices of these tanks.

The system of cleansing is as follows. The tannery effluent is pumped into the tanks and mixed with chloride of lime and chromate salts. The mixture is agitated for 6 hr. by compressed air. The mixture is left to settle until the cone of the tanks is filled with precipitate and the water above is odourless and pure.
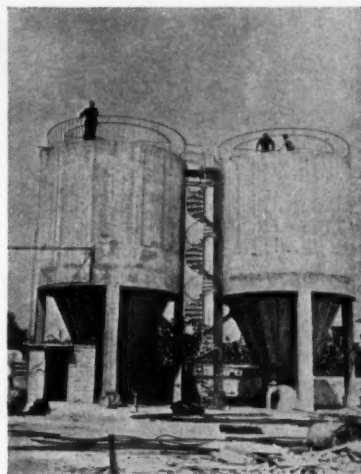
The two 30-ft. high concrete tanks in which the effluent from Cavada Brothers tannery in Athens is purified. The compressor house is bottom left and compressed air mains are at base of each cone.

Precipitation period is between 1 and 2 hr. The compressed air not only agitates the water/chemical mixture, but also provides oxygen for complete oxidation.

After settlement, the purified effluent is piped off to the sewage main and the precipitate stored in an underground tank and removed periodically for dumping in an unpopulated part of the countryside outside the city.

OCTOBER 10 Symposium on **surface effects and liquid behaviour** at the Royal Institution, London, W.1. Details from the Institution of Chemical Engineers, 16 Belgrave Square, Westminster, London, S.W.1.

OCTOBER 11 TO 13 **British Institute of Management** National Conference in Harrogate. Details from Management House, 80 Fetter Lane, London, E.C.4.

OCTOBER 11 TO 14 Symposium on **inelastic scattering of neutrons in solids and liquids,** to be held in Vienna. Details from the organisers, I.A.E.A., 11 Kartner Ring, Vienna 1, Austria.

OCTOBER 16 TO 29 A British Council Course on the **non-destructive testing of materials** in London. Details from Miss H. Bailey, 64 Davies Street, London, W.1.

OCTOBER 17 TO 19 International Congress on the **Technology of Plastics Processing.** Details from N.V. 't Readthuys, Tesselschadestraat 5, Amsterdam, Holland.

OCTOBER 19 TO 26 International **macroPlastic Exhibition** in Utrecht. Details from Exhibition Consultants Ltd., 11 Manchester Square, London, W.1.

OCTOBER 19 TO 26 **Interkama** International Congress and Exhibition for **Instrumentation and Automation** in Düsseldorf. Details from Nordwestdeutsche, Ausstellungs-Gesellschaft mbH. (NOWEA), Düsseldorf.

OCTOBER 23 TO 30 Thirty-second **Congres International de Chimie Industrielle** in Barcelona. Details from the organisers, Chimie et Industrie, Soprodoc, 28 Rue Saint-Dominique, Paris 7.

OCTOBER 24 TO 27 **Iron and Steel Engineers Group** of the Iron and Steel Institute meeting in Scunthorpe. Details from the Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1.

OCTOBER 24 TO 27 Symposium on **chemical effects of nuclear transformations** in Prague. Organised by International Atomic Energy Agency, Vienna.

OCTOBER 29 TO NOVEMBER 7 Standard course on **reactor techniques** at the Harwell School. Details from the principal, Reactor School, A.E.R.E., Harwell, Didcot, Berks.

NOVEMBER 1 AND 3 The autumn meeting of the Institute of Welding to be held in London and will be devoted to the **metallurgy of welding and brazing.**

NOVEMBER 8 TO 10 Conference on **non-destructive testing in electrical engineering.** Details from the organisers, the Institution of Electrical Engineers, Savoy Place, London, W.C.2.

NOVEMBER 28 TO DECEMBER 2 Symposium on **experimental and test reactors** in Vienna. Information from the organisers, I.A.E.A., 11 Kartner Ring, Vienna 1, Austria.

NOVEMBER 29 TO DECEMBER 2 **The Corrosion and Metal Finishing Exhibition** to be held at Olympia. Organised by Leonard Hill Ltd. Details from the Director, the Corrosion and Metal Finishing Exhibition, 9 Eden Street, London, N.W.1.

NOVEMBER 30 TO DECEMBER 2 Symposium on **steels for nuclear reactor power circuits** at Church House, London, S.W.1. Details from the Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1.

NOVEMBER 30 TO DECEMBER 2 Second **Reinforced Plastics** Conference at the Cafe Royal, London. Information from the British Plastics Federation, 47-48 Piccadilly, London, W.1.

DECEMBER 6 Lecture on the study on **electro-precipitator performance in relation to particle size distribution, level of collection efficiency and power input,** by D. O. Heinrich, at the Geological Society, Burington House. Details from the Institution of Chemical Engineers.

DECEMBER 12 TO 14 Winter meeting of the American Nuclear Society, including conference on **hot laboratories and equipment and the Atomic Industry Exhibition,** in San Francisco, California, U.S.A. Organised by the American Nuclear Society. Details from the secretary of the society, Mr. O. du Temple, c/o John Crerar Library, 86 East Randolph Street, Chicago 1, Illinois, U.S.A.

DECEMBER 14 TO 16 Annual conference of the **Atomic Industrial Forum.** Information from the forum, 3 East 54th Street, New York, 22.

DECEMBER 15 TO 16 Meeting of the **Powder Metallurgy** Joint Group of the Iron and Steel Institute to be held at Church House, Great Smith Street, London, S.W.1. Details from the group secretary, 17 Belgrave Square, London, S.W.1.

CORROSION & METAL FINISHING EXHIBITION

Sir Alexander Fleck, K.B.E., F.R.S., president of the Society of Chemical Industry, will open the Corrosion and Metal Finishing Exhibition. The ceremony will take place at 11 a.m. on Tuesday, November 29, in the Empire Hall, Olympia, where the exhibition will remain open until Friday, December 2. That such a distinguished chemist and industrialist is associating himself with the exhibition illustrates the importance of corrosion, both as an electrochemical phenomenon and an industrial problem.

This year's Corrosion and Metal Finishing Exhibition will be the biggest-ever demonstration of the products and services that are now available to combat corrosion. So far nearly 100 exhibitors have reserved stands and the final total may be higher. Of special interest to the chemical industry will be the displays of corrosion-resistant plant and equipment in plastics, special metals, etc. Linings and coatings to prevent corrosion will also be prominently featured.